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THE TRANSITION CURVE

BY OFFSETS AND BY DEFLECTION ANGLES.

BY

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FIRST EDITION.
FIRST THOUSAND.

NEW YORK:
JOHN WILEY & SONS,
53 EAST TENTH STREET.
1893.

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BY
C. L. CRANDALL.

ROBERT DRUMMOND,
Electrotyper,
446 Pearl Street
New York.

FERRIS BROS.,
Printers,
326 Pearl Street,
New York.

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PREFACE.

MUCH has been written upon the subject of transition curves within the past few years, and the theory and practice have been accurately worked up for small central angles, notably in the "Holbrook Spirals." Accurate methods are here, it is believed for the first time, developed for the true transition curve, curvature increasing directly with the distance, which will hold for large central angles for both the offset and the deflection methods. The extension of the limits to include long transition curves with large central angles increases the flexibility of the alignment of a railroad, which will tend to economy of construction in all but the most easy country.

The offset method is worked up for use during location and the greater part of construction on account of its extreme simplicity; the increased labor over that required for simple curves being almost insignificant.

The method by deflections with transit and chain will usually be preferred for curves over 200 to 300 feet in length, in running centers on the finished roadbed, for laying track, or other accurate work. Table III will give the deflections for any true transition curve connecting a circular curve with a tangent, or connecting the two branches of a compound curve, with accuracy for all central angles of transition curve up to 60°. The deflections taken out for the most common curves can be conveniently tabulated on the blank pages inserted for the purpose.

While intended primarily for the use of civil engineering students, it is believed that the complete set of tables given will render the methods at least as rapid and convenient in actual use in the field as the more restricted or approximate ones now in use.

Special acknowledgment is due to H. N. Ogden, C.E., formerly an instructor here, for carefully revising the text.

CORNELL UNIVERSITY,
ITHACA, N. Y., Jan., 1893.

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TRANSITION CURVES.

1. Necessity for Transition Curves.—The road bed upon a tangent or straight track is made level transversely; upon a circular curve it is inclined toward the center to counteract centrifugal force. The change from the one to the other must be gradual for easy riding, and to prevent twisting the trucks. Hence if the inclination of the road-bed is to be proportional to the centrifugal force at every point, a transition curve must be used, in which the curvature increases directly with the distance, in passing from the tangent to the circular curve.

2. Different Kinds in Use.—Rankine (*Civil Engineering*) gives the credit of first laying out railroad curves with a gradual increase of curvature, starting from the tangent, to Mr. Gravatt about 1828; of using such a curve to connect the tangent and main circular curve, to Mr. Wm. Froude about 1842,—their methods being first published in 1860-1.

In this country transition curves have come into use within the last ten to twelve years. The true transition curve, curvature increasing directly with the distance, was described in *The Railroad Gazette*, Dec. 3, 1880, by Ellis Holbrook. *The Railroad Spiral*, a curve made up of circular arcs compounded, by W. H. Searles, was published in 1882. The cubic parabola, in which the curvature increases with the distance along the tangent, was described by C. D. Jameson and E. W. Crellin in the *Railroad and Engineering Jour.* in 1889. The Froude curve, as worked up by A. M. Wellington, was described in the *Engineering News* in 1890. These bring out the more important classes, although the list is far from complete.

All but the last were worked out to be run with transit and chain, the deflections being given for several curves with

different rates of increase of curvature for flexibility; the last was worked up to be run with transit, or by ordinates from the circular curve and from the tangent, as preferred. It is the only one of the list which is worked up for a curve of any length or of any offset from the tangent to the main circular curve; the field-work during location is reduced to a minimum by offsetting from the tangent directly to the circular curve, but the fundamental assumptions become inconsistent when the curve includes a large central angle.

THEORY.

3. Equation of Curve.—In Fig. 1, let EGE' be a circular curve with centre C and tangents EK and $E'K$. It is

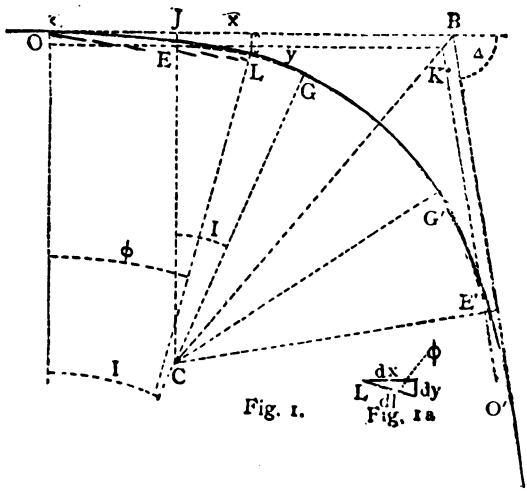


Fig. 1.

Fig. 1a

evident that if we begin at G to reduce the curvature directly with the distance, and continue the reduction until the curvature is zero, using the same central angle I as for the corresponding portion of the circular curve, the new curve will pass outside the old, requiring a tangent OB parallel with KE, and at some distance as JE from it.

E is called the $P.C.$, as usual; O, the $P.T.C.$; $\mathcal{G}$, the $P.C_1.$; $\mathcal{T}$, the $P.T.C_1.$; E', the $P.T.$; O', the $P.T_1.$

Since the curvature is zero at O and increases directly with the distance, the ratio of the curvature and distance increments, $d\phi$ and dl, must increase with l, i.e.,

$$\frac{d\phi}{dl} = 2kl, \quad \ldots \ldots \ldots \quad (1)$$

where $2k$ is a constant for any one curve, but varies for different curves.

Integrating,

$$\phi = kl^2, \quad \ldots \ldots \ldots \quad (2)$$

where ϕ is the central angle up to the point L, l the length, and k a constant.

In the right differential triangle, Fig. 1*a*,

$$\begin{aligned} dy &= dl \sin \phi \\ &= dl \sin kl^2, \quad \text{since} \quad \phi = kl^2 \text{ by (2).} \end{aligned}$$

The expansion of the sine in terms of the angle, by Trigonometry, is

$$\sin t = t - \frac{t^3}{3!} + \frac{t^5}{5!} - \frac{t^7}{7!} + \ldots,$$

where ! denotes a factorial number, i.e., $3! = 1 \times 2 \times 3 = 6$, etc.

Substituting,

$$dy = dl\left(kl^2 - \frac{k^3l^6}{3!} + \frac{k^5l^{10}}{5!} - \frac{k^7l^{14}}{7!} + \ldots\right).$$

Integrating,

$$y = \frac{kl^3}{3} - \frac{k^3l^7}{42} + \frac{k^5l^{11}}{1320} - \frac{k^7l^{15}}{75600} + \ldots \quad (3)$$

Restoring ϕ for kl^2,

$$y = \frac{l\phi}{3} - \frac{l\phi^3}{42} + \frac{l\phi^5}{1320} - \frac{l\phi^7}{75600} + \ldots,$$

where ϕ is in π-measure, coming from the development of the sine in series.

For ϕ in degrees $\left(\phi = \phi^\circ \frac{\pi}{180} = .017453\phi^\circ\right)$,

$$y = l\left[\tfrac{1}{6}(.017453)\phi^\circ - \tfrac{1}{4\,2}(.017453)^3\phi^{\circ 3} + \tfrac{1}{1\,3\,2\,0}(.017453)^5\phi^{\circ 5} - \tfrac{1}{7\,5\,6\,0\,0}(.017453)^7\phi^{\circ 7} + \right],$$

$$y = lC, \quad \ldots\ldots\ldots \quad (4)$$

where C varies with ϕ°; it can be taken from Table II, with ϕ° as argument.

From Fig. 1*a*,

$$dx = dl \cos \phi$$
$$= dl \cos kl^2, \text{ since } \phi = kl^2 \text{ by (2).}$$

The expansion of the cosine in terms of the angle, by Trigonometry, is

$$\cos t = 1 - \frac{t^2}{2!} + \frac{t^4}{4!} - \frac{t^6}{6!} + .$$

Substituting,

$$dx = dl\left(1 - \frac{k^2l^4}{2!} + \frac{k^4l^8}{4!} - \frac{k^6l^{12}}{6!} + \right).$$

Integrating,

$$x = l - \frac{k^2l^5}{10} + \frac{k^4l^9}{216} - \frac{k^6l^{13}}{9360} + \ldots\ldots \quad (5)$$

Restoring ϕ for kl^2,

$$x = l - \frac{l\phi^2}{10} + \frac{l\phi^4}{216} - \frac{l\phi^6}{9360} + .$$

For ϕ in degrees,

$$x = l - l\left[\tfrac{1}{1\,0}(.017453)^2\phi^2 - \tfrac{1}{3\,4\,6}(.017453)^4\phi^4 + \tfrac{1}{5\,5\,4\,5\,6\,0}(.017453)^6\phi^6 - \right],$$

$$x = l - lE, \quad \ldots\ldots\ldots \quad (6)$$

where E varies with ϕ°; it can be taken from Table II with ϕ° as argument.

4. Coördinates of Center.—Since the increment to the central angle, $d\phi$, is in π-measure, = arc dl divided by radius of curvature ρ, we have from (1),

$$\frac{dl}{d\phi} = \rho, \quad = \frac{1}{2kl}. \quad \ldots\ldots \quad (7)$$

At the $P.C_1.$, $\rho = R$, the radius of the circular curve; $\phi = I$, the central angle of the circular curve from $P.C.$ to $P.C_1$.

Therefore, from (2) and (7),

$$I = kl_1^2, \quad = \frac{l_1}{2R}, \quad \ldots\ldots \quad (8)$$

where l_1 = the length of the transition curve to $P.C_1$.

But $R = \frac{5730^*}{D}$; $I^\circ = I\frac{180}{\pi} = 57.30I$.

$$\therefore I^\circ = \frac{l_1 D}{200}, \quad = 28.65\frac{l_1}{R}, \quad \ldots\ldots \quad (9)$$

$$k = \frac{1}{2Rl_1} = \frac{D}{11460l_1}. \quad \ldots\ldots \quad (10)$$

If x_1 and y_1 are the coördinates of $P.C_1.$, and x', F, those of the $P.C.$ (see Fig. 2),

$$\left.\begin{aligned} F &= y_1 - R(1 - \cos I) \\ x' &= x_1 - R\sin I \end{aligned}\right\}, \quad \ldots\ldots \quad (11)$$

while the coördinates of the center will be x' and $F + R$.

5. Deflection Angles.—With the instrument at station O, Fig. 2 ($P.T.C.$, or $P.T_1.$), the tangent of the deflection angle d_0 can be found by dividing y by x, using the values from equations (3) and (5), thus:

$$\tan d_0 = \frac{y}{x} = \frac{kl^2}{3} + .009\,523k^3l^6 + .000\,167k^5l^{10} + .$$

* If curves from 8° to 16° be run with 50-foot chords, curves from 16° to 32° with 25-foot chords, and all sharper than 32° with 10-foot chords, the above value will be correct to the nearest foot. All the accompanying tables are computed on this basis.

The expansion of the angle in terms of the tangent is, by Trigonometry,

$$t = \tan t - \tfrac{1}{3}\tan^3 t + \tfrac{1}{5}\tan^5 t - .$$

Substituting, and retaining nothing higher than k^5,

$$d_0 = \frac{kl^2}{3} - .002\,823k^3l^6 - .000\,068k^5l^{10}$$

$$= \frac{I}{3}n^2 - .002\,823I^3n^6 - .000\,068I^5n^{10},$$

by using for k its value $I \div l_1^2$ from (8), and calling the ratio

$$l \div l_1 = n.$$

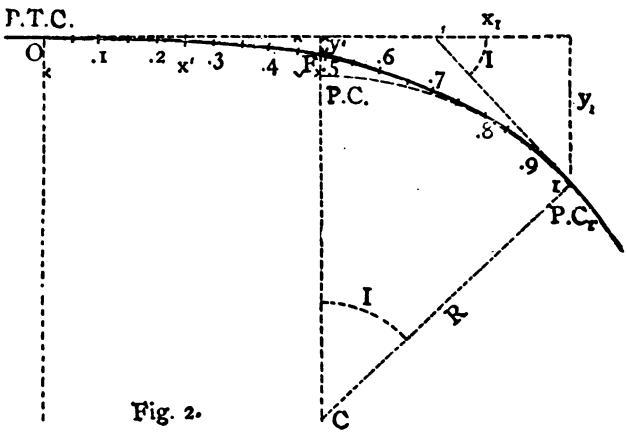


Fig. 2.

d_0 and I are in π-measure: to reduce to degree-measure, multiply by $\frac{\pi}{180} = .017\,453$, giving

$$d_0^\circ = \frac{I^\circ}{3}n^2 - .000\,023\,22\left(\frac{I^\circ}{3}\right)^3 n^6 - .000\,000\,001\,53\left(\frac{I^\circ}{3}\right)^5 n^{10};$$

$$d_0^\circ = \frac{I^\circ}{3}n^2 - B_0, \quad \ldots \ldots \ldots \ldots \ldots \quad (12)$$

i.e., *the deflection varies approximately as the square of the distance, and is nearly equal to one third the central angle subtending the same arc.*

B_0, in thousandths of a degree, can be taken from Table III with $I°$ as argument.

With the instrument at an intermediate point, x'', y'',

$$\begin{aligned}\tan d'' = \frac{y - y''}{x - x''} = \frac{k}{3}(l^2 + l''^2 + ll'') \\ + k^3[\tfrac{1}{10}\tfrac{1}{8}(l^6 + l''^6) + \tfrac{3}{70}(l^5 l'' + ll''^5) \\ + \tfrac{8}{10}\tfrac{3}{8}(l^4 l''^2 + l^2 l''^4 + l^3 l''^3)] + k^5[.000\,167(l^{10} + l''^{10}) \\ + .002\,909(l^9 l'' + ll''^9) + .008\,985(l^8 l''^2 + l^2 l''^8) \\ + .016\,604(l^7 l''^3 + l^3 l''^7) + .024\,223(l^6 l''^4 + l^4 l''^6) \\ + .027\,556 l^5 l''^5].\end{aligned}$$

From which, by finding the value of the angle in terms of the tangent, and substituting the value of k as before,

$$d''° = \frac{I°}{3l_1^2}(l^2 + l''^2 + ll'') - \text{Correction.}$$

$$d''° = \frac{I°}{3}(n^2 + n''^2 + nn'') - B'', \quad \ldots\ldots \quad (13)$$

where B'' contains the terms involving I^3 and I^5, a rapidly converging series.

With the instrument at Sta. 1 ($n'' = 1$),

$$d_1° = \frac{I°}{3}(n^2 + 1 + n) - \text{Correction}$$

$$= \frac{I°}{3}A_1 - B_1. \quad \ldots\ldots\ldots\ldots \quad (14)$$

With the instrument at Sta. .5 ($n'' = \frac{1}{2}$),

$$d°_{.5} = \frac{I°}{3}(n^2 + \tfrac{1}{4} + \tfrac{1}{2}n) - \text{Correction}$$

$$= \frac{I°}{3}A_{.5} - B_{.5}. \quad \ldots\ldots\ldots\ldots \quad (15)$$

Instrument at Sta. .25 ($n'' = \frac{1}{4}$),

$$d^\circ_{.25} = \frac{I^\circ}{3}(n^2 + \tfrac{1}{16} + \tfrac{1}{4}n) - \text{Correction}$$

$$= \frac{I^\circ}{3}A_{.25} - B_{.25}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Instrument at Sta. .75 ($n'' = \frac{3}{4}$),

$$d^\circ_{.75} = \frac{I^\circ}{3}(n^2 + \tfrac{9}{16} + \tfrac{3}{4}n) - \text{Correction}$$

$$= \frac{I^\circ}{3}A_{.75} - B_{.75}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

A and B can be taken from Table III, with n'', n, and I° as arguments. B is in thousandths of a degree. Second differences should be used in interpolating for A when I° is large.

6. Construction of Tables.—These formulas are too complicated for convenient use, although all the series converge rapidly. Tables thus become necessary.

Table I.—l_1, the length of curve, for a given D is first assumed in values increasing by 20 feet from 40 to 700 ft.; I°, the central angle, can be found by (9); x_1, y_1, the coördinates of $P.C._1$, are found by (4) and (6) by the aid of Table II;* x', F, the coördinates of the $P.C.$ of the circular curve, are found by (11); l', the length of the transition curve from the $P.T.C.$ to the $P.C.$, is most conveniently found by assuming a value a little less than $[x' + (l_1 - x_1) + 32]$ for l in (5), and noting the resulting value of x; a second assumption may sometimes be necessary to bring the value of l used in the higher terms to the nearest tenth, which will usually give $l' - x'$ with sufficient accuracy; $l' - x'$ is tabulated as e; ϕ', the central angle corresponding with l', will $= (l' + l_1)^2 I$, by (2); when y', the ordinate opposite the $P.C.$, can be found by (4), or it can be found from (3) without using ϕ'; $l_1 - l'$ will give the length of the second portion of the transition curve; $100I^\circ + D +$ arc excess, taken from Table V,† will give the

* They were actually computed by (3) and (5), so that occasionally there may be a slight discrepancy in the last place.

† Arc excess = excess of circular arc over the sum of the chords from the $P.C.$ to the $P.C._1$.

length of the circular arc for the corresponding portion; the difference between the transition arc and circular arc is tabulated as e'; $e + e' = \frac{l_1}{2} - x'$ – arc excess.

Table II gives C of (4) and (E) of (6), rendering the computation of the coördinates, x and y, of any point of the curve extremely simple.

Table III gives A and B for computing the deflection angles by (12), (14), (15), (16), (17), for 20 equidistant stations on the curve, with the instrument at each of 5 different ones; B is in thousandths of a degree, and can be interpolated for intermediate values of ϕ and I. A should be interpolated by second differences when I is large, or directly computed if more convenient. As great flexibility is thus given in the field-work in passing obstructions, etc., as with circular curves.

All the tabular quantities were computed to one or more places than have been retained, and they have been checked, in type, by second differences. It is confidently believed that no errors of importance will be discovered, and no inaccuracies which can affect the best grade of field-work.

Linear interpolation will usually be sufficient for intermediate values; second differences may be preferred for F and y in some parts of the table.

x_1, y_1, will usually be of use when an obstruction, or other local condition, prevents the use of the ordinary methods in the field.

PRACTICE.

7. Field-work by Offsets.—It will usually be most convenient during location and construction to simply allow the offset F between the tangent and circular curve, and the excess in length when important, without running the transition curve. Two hubs are then required at the $P.C.$, and also at the $P.T.$, one at the $P.C.$ or $P.T.$ proper, and the other on the tangent opposite, the distance between being F, one being set as a foresight and the other by offset. The instrument when brought up is placed over the offset hub, requiring the backsight to be similarly offsetted; or, with a table of natural functions, the vernier may be set to

$$\cot^{-1}(\text{distance} \div \text{offset});$$

or, if the offset is small, at the angle in minutes

$$= \frac{\text{offset}}{.029 \times \text{distance in stations}}.$$

On a curve the offset should be multiplied by cos $(nD + 2)$,* and the long chord taken for distance, in the above expression, when failing to offset the back flag.

In plotting, the radius of the circle is increased by the offset in fixing the center from the tangent, while the radius is used in describing the arc, thus leaving the offset F at the tangent point.

The increased labor from transition curves thus run is very small.

Intermediate points on the transition curve, if required, can be found by ordinates from the tangent proportional to the cube of the distance from the $P.T.C.$, or from the circle proportional to the cube of the distance from the $P.C._1$, near enough during construction, those at the $P.C.$ being nearly equal to one half of F. The true coördinates are readily found from Table II if more accuracy is required.

EXAMPLE 1. At station 674 a 12° curve to the left begins. Required the data for a 500′ transition curve (front tangent not fixed).

From Table I for $l_1 = 500$, $F = 21.60$, $e = .4$, $e' = 1.8$, $x' = 247.7$.

$\therefore$ at sta. 674, $-(e + e') = 673 + 97.8$, to allow for excess in length, erect a perpendicular with transit or chain = 21.60; place hub; set transit over it with 0° of vernier parallel to tangent and run curve as usual. The $P.T.C.$ will be $673 + 97.8 - x' = 671 + 50$, and the $P.C._1$, $676 + 50$.

Approx. ordinates:

$$\text{Sta. } 672, \quad \frac{21.60}{2} + 5^3 = .0864;$$

$$672 + 50, \quad .0864 \times 2^3 = .7;$$

$$673 \qquad .0864 \times 3^3 = 2.3;$$

$$673 + 50, \quad .0864 \times 4^3 = 5.5;$$

and the same values for corresponding stations from the circle.

The true coördinates for any point can be computed by (4) and (6), if needed for greater accuracy. Thus, for sta. 673: Table I gives $I = 30°$, (2) gives $\phi° = (\frac{1}{60})^2\, 30° = 2°.7$. Table II gives $C = .0157$, $E = .00022$. $\therefore y = 150\, C = 2.36$; $x = 150 - 150E = 150$.

---

* n = distance in stations; D = degree of curve.

8. Field-work by Deflections.—For track centers the transition curve is best run with a transit. From F, I and l_1 are readily found from Table I, interpolating if necessary. Having l_1, the number of stations (an aliquot part of 20) can be taken so that they will be no farther apart than on the circular curve. The instrument points for running the curve are then decided upon, the corresponding numbers are taken from Table III to multiply by $I \div 3$ for the deflections, subtracting the corrections when important. The curve is then run in the usual way with transit and chain, but with short stations.

Blank pages are inserted with Table III in order to preserve the deflections computed for the more common transition curves.

Regular stations can be used if preferred, it adding slightly to the labor of finding A in the deflection formula.

When the curve can be run with the instrument at the $P.T.C.$, —and $I°$ is not over 15° to 20°, the deflections can be taken by (12) equal $\frac{I}{3}n^2$, without the use of Table III.

Strictly, the distances measured should be along the arcs, and not along the chords; the chords can be shortened by Table V to allow for this whenever the accuracy of the chaining will warrant; the maximum discrepancy is one inch per 100 feet, if the chords are as short as would be used for circular arcs of the same curvature.

EXAMPLE 1.—Find the deflections for a 9° curve with a 10.48-ft. offset. Table I: $I = 18°$; $I \div 3 = 6°$; $l_1 = 400'$; requiring 10 chords each 40′. With instrument at $P.T.C.$, from Table III:

$$d_0{}^1 = .01 \times 6° \qquad = 0°.06 = 0° \ 3'.6;$$

$$d_0{}^2 = .04 \times 6 \qquad = 0 \ .24 = 0 \ 14 .4;$$

. . . . . .

$$d_0{}^9 = .81 \times 6 - .003 = 4 \ .857 = 4 \ 51 .4;$$

$$d_0{}^1 = 1 \ \times 6 - .005 = 5 \ .935 = 5 \ 59 .7.$$

On reaching sta. 1 or the $P.C._1$, set up, backsight on sta. O, deflect $18° - d_0{}^1$ for tangent at sta. 1; then run the remainder of the circular curve as usual. On reaching the $P.T.C._1$, the second transition curve can be run continuously by placing the circle so that the vernier shall read $I°$ for the tangent at $P.T.C._1$, and zero when parallel with the ta

gent at the *P.T.*, and then setting the following readings computed from Table III.:

Instrument at $P.T.C._1$:

$$d_1{}^{.9} = 2.71 \times 6^\circ \quad = 16^\circ.26 \quad = 16^\circ\ 15'.6;$$

$$d_1{}^{.8} = 2.44 \times 6 \quad = 14\ .64 \quad = 14\ \ 38\ .4;$$

. . . . . .

$$d_1{}^{.1} = 1.11 \times 6 \ - .004 = \ 6\ .656 = \ 6\ \ 39\ .4;$$

$$d_1{}^{.0} = 1 \quad \times 6 \ - .005 = \ 5\ .995 = \ 5\ \ 59\ .7.$$

9. Best Length of Curve.—The rate of change of elevation of outer rail preferred by trackmen, in passing from the tangent to the circular curve, varies from 1 to 2 inches per station; the elevation on the circular curve varies from one half to three fourths of an inch, to one inch for very high speeds, per degree, until a maximum of from 5 to 9 inches is reached. This would require from 25 to 75 feet of transition curve per degree of main curve up to a length of some 700 feet.

On short tangents and short curves short transition curves will be required to prevent serious overlapping. On the other hand, a circular curve with transition ends leading to the tangents will usually approach nearer to the shape of a contour around a spur or up a narrow valley than a circular curve with tangents, thus using the longer curves in extending the combinations available for fitting the ground in rugged topography. This flexibility will also be found very convenient in running track centers over crooked portions of the line, as the line can be better fitted to the road-bed, and small discrepancies in re-running the curves from imperfectly recovered points can be taken care of in the offset, as any offset within the limits of the tables can be used by interpolation.

10. Compound Curves.—In Fig. 3, let C be the center of the sharper curve of radius R and degree D; C'' that of the flatter curve of radius R'' and degree D''; F_2 the perpendicular distance $E'J'$ between the curves on the line joining their centers; $OG''G$, the transition curve, joining the first curve at G, the second at G'', and its own tangent OB (not the tangent to the compound curve) at O; l_1, the length OG; l'', the length OG''; l_2, the length $G''G$; e_2, the excess in length by

using the transition curve. Call G the $P.T.C._2$; E' or J', the $P.C.C.$; G'' the $P.C._2$; E'' the $P.T.''$; and O the $P.T._2$.

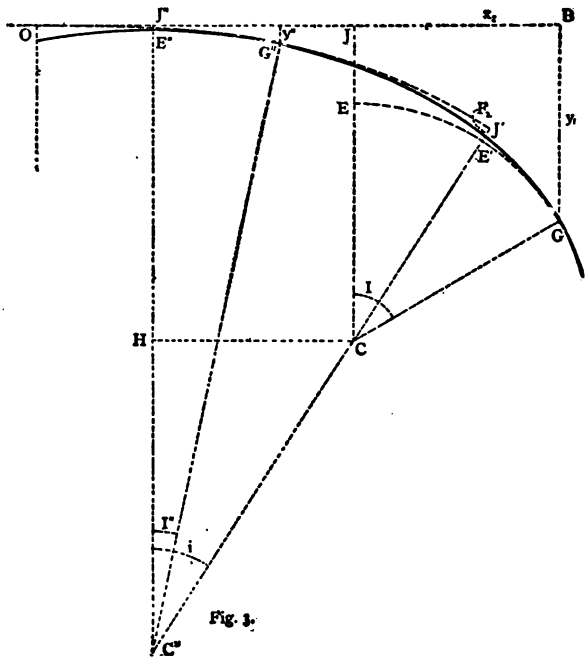


Fig. 3.

Since the curvature increases directly with the distance

$$\left.\begin{aligned} l'' &= l_1 \frac{D''}{D}; \\ l_2 &= l_1 - l'' = l_1 \frac{D - D''}{D}. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (18)$$

By equations (8) and (9),

$$I'' = \frac{l'' D''}{200}, \quad = I \left(\frac{l''}{l_1}\right)^2 . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

The coördinates of the center C are x' and $F + R$, taken from Table I for the D° curve; those for C'' are x'' and $F'' + R''$, taken from Table for the D'' curve with l'' as argument.

In the right triangle HCC'', HC, and HC'' are known from the above, giving

$$\left.\begin{aligned}
\tan i &= \frac{HC}{HC''} = \frac{x' - x''}{k'' + R'' - F - R};\\
CC'' &= \frac{HC''}{\cos i} = \sqrt{\overline{HC}^2 + \overline{HC''}^2};\\
F_2 &= R'' - R - CC'';\\
GE', \text{ or } P.T.C._2 \text{ to } P.C.C. &= \frac{I - i}{D}100;\\
J'G'', \text{ or } P.C.C. \text{ to } P.C._2 &= \frac{i - I'}{D''}100;\\
e_2 &= l_2 - (GE' + J'G'') - \text{arc excess};\\
&= l_2 - 100\left(\frac{I - i}{D} + \frac{i - I'}{D''}\right) - \text{arc excess};
\end{aligned}\right\} \quad \ldots \quad (20)$$

where "arc excess" is the sum taken from Table V for the proper lengths for the two circular arcs.

Computing F_2 and e_2, for different cases, they are found to be the same as given by Table I, with $D - D''$ and l_2 as arguments, up to about $Dl_1 = 8000$; i.e., up to $D = 12°$, $l_1 = 680'$; $D = 20°$, $l_1 = 400'$; etc. For greater values, F_2 should be computed by (20) for accuracy, although the error is not large at the limits of the Table.

Computing GE', the distance from the $P.T.C._2$ to the $P.C.C.$ on the sharper curve, by (20), it is found equal to $l_2 + 2$, up to about $Dl_1 = 4000$; leaving $J'G''$, the distance from the $P.C.C.$ to the $P.C._2$ on the flatter curve, $= l_2 + 2 - e_2 -$ arc excess. For much larger values these distances should be computed by (20).

Hence, in using the offset method of allowing for the transition curve, assume a suitable l_2 (or F_2) for a $D - D''$ curve; take out the corresponding F (or l_1) and $e + e'$ from Table I; run the circular curve to E', the $P.C.C.$, as usual (the front curve not being closely fixed in position); offset radially an amount F_2; set up at J' and continue as usual, allowing for $e + e'$ when important.

In using the deflection method, assume l_2 as above; find F_2 and e_2 for a $D - D''$ curve by Table I, and l_1 and l'' by (18); then $GE' = l_2 + 2$, $J'G'' = l_2 + 2 - e_2 -$ arc excess. Lay off GE' and $J'G''$; set up at G, the $P.T.C._2$, and run the transition curve of length l_1 as usual until G'', the $P.C._2$ (distant l_2 from G), is reached, the last deflection being interpolated in Table II. Set up at the $P.C._2$; backsight to the $P.T.C._2$; then deflect the last deflection at the $P.T.C._2$, less I'', for a tangent at the $P.C._2$; the D'' curve can then be run as usual.

If Dl_1 exceeds the limits given above, F_2, e_2, GE', and $J'G''$ must be computed by (20), as already indicated.

To run the curve in the other direction: locate O, the $P.T._2$, by a tangent to the circular arc at E'', the $P.T.''$, measuring the x'' of Table I backward and offsetting F''; or locate an instrument point of Table III, by coördinates from E'' or G'' by Table II, the coördinates of both E'' and G'' being known; then run the curve as usual. It can also be run with the instrument at G'', computing A of the deflection formula by (13), and interpolating B from Table III.

EXAMPLE 1.—A 10° curve compounds to a 4° with a 3.92 ft. offset, at sta. 196 + 40. Find the data for running the transition curve with a transit.

Table I, for $F_2 = 3.92$, and $D - D'' = 6°$, gives $l_2 = 300$ ft.

By (18), $l_1 = l_2 \frac{D}{D - D''} = 500$ ft.; $l'' = l_1 - l_2 = 200$ ft.

Table I, for $D = 10°$, $l_1 = 500$, gives $I = 25°$, $F = 18.05$, $x' = 248.4$; for $D'' = 4°$, $l'' = 200$, gives $I'' = 4°$, $F'' = 1.16$, $x'' = 100$.

Table IV gives $R = 573$, $R'' = 1432.5$.

$Dl_1 > 4000$, requiring a computation for GE' by (20) for strict accuracy.

$$\tan i = \frac{248.4 - 100}{1.16 + 1432.5 - 18.05 - 573} = \frac{148.4}{842.61},$$

giving $i = 9°.989$.

$$GE' = \frac{25 - 9.989}{10} 100 = 150.11 \text{ ft.}$$

$$J'E'' = \frac{9.989 - 4}{4} 100 = 149.72 \text{ ft.}$$

$$P.T.C._2 = \text{sta. } 196 + 40 \quad -(1 + 50.1) = 194 + 89\ 9;$$

$$P.C._2 \quad = \text{“ } 194 + 89.9 + (3 + 00) \quad = 197 + 89.9.$$

Using 10 stas. with 50-ft. chords for the 500′ curve, G'', or the $P.C._2$, 200′ from O, will be sta. .4.

Table III, instrument at $P.T.C._2$, or G,

$$d_1 \cdot^9 = 2.71 \times 8\tfrac{1}{2}° \qquad = 22° 35';$$
$$d_1 \cdot^8 = 2.44 \times 8\tfrac{1}{2} \qquad = 20\ \ 20;$$
$$\cdots\cdots\cdots\cdots$$
$$d_1 \cdot^4 = 1.56 \times 8\tfrac{1}{2}° - .001 = 12\ \ 59.8.$$

Zero at $P.T.C._2$ makes an angle = 25° with tangent to 10° curve.

Tangent at $P.C._2$ makes with backsight an angle = 12° 59′.8 − 4° = 8° 59′.8.

11. Tangent Distance with Transition Curve. —Given the central angle Δ, the degree of the curve D, and the offset F, to find the tangent distance T'.

The effect of the transition curve is to move the circular curve from the position *HLM* to *ENE'*, the perpendicular dis-

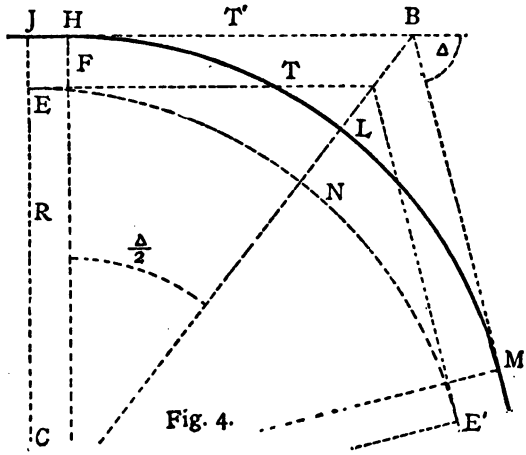


Fig. 4.

tance between the tangents being *F*. In the right triangle *JCB*,

$$JB = (EC + JE) \tan \frac{\Delta}{2},$$

or

$$T' = (R + F) \tan \frac{\Delta}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

$$= T + F \tan \frac{\Delta}{2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

$T_1 = R \tan \frac{\Delta}{2}$, being the tangent distance without the transition curve, found by Table VI, or by computation.

If the curve is to be run by deflections, x' must be added to T' to reach back to the *P.T.C.*, giving

$$T_1 = T + F \tan \frac{\Delta}{2} + x'. \quad . \quad . \quad . \quad . \quad (23)$$

x' can be taken from Table I with D and F as arguments.

EXAMPLE 1. Write out the transit notes for a 6° curve, with $P.I.$, point of intersection of the two tangents, = sta. 721 + 52.7; $\Delta = 17° 21'$; $F = 2.51$ ft.

By (21), $T' = (955 + 2.51) \tan 8° 40\frac{1}{2}' = 146.1$.

Length of curve $= \frac{\Delta}{D} = 2.892$ stas.

TRANSIT NOTES.

Sta.	Point.	Curve or Bearing.	Vernier.
+ 95.8	$P.T.$, $F = 2.51$	S. 35° 30′ W.	8° 40½′
2			5 48
1			2 48
+ 6.6	$P.C.$, $F = 2.51$	6° R.	
720		S. 18° W.	

For track centers, or transition curve run with transit:

By (23) and Table I, $T_1 = 146.1 + 119.9 = 266$. $I° = 7°.2$.

Length of circular curve $= \frac{\Delta - 2I}{D} = 0.492$ stas.

Length of transition curve, Table I, = 240 ft., requiring 4 60-ft. chords.

Table III, for $I = 7°.2$:

Instrument at sta. O: $d_0^{.25} = 0° 09'$; $d_0^{.5} = 0° 36'$; $d_0^{.75} = 1° 21'$; $d_0^{1} = 2° 21'$.

Instrument at sta. 1: $d_1^{1} = 7° 12'$; $d_1^{.75} = 5° 33'$; $d_1^{.5} = 4° 12'$; $d_1^{.25} = 3° 09'$; $d_1^{0} = 2° 24'$.

TRANSIT NOTES.

Sta.	Point.	Curve or Bearing.	Vernier.	Remarks.
724 + 15.9⊙	$P.T._1$	S. 35° 30′ W.	2° 24′	Vernier = 2° 24′ for B. S.
.25			3 09	
.5			4 12	
.75			5 33	
+ 75.9⊙	$P.T.C._1$		1 28½	Vernier = 8° 40½′ for B. S. (= $I°$ + 1° 28½′)
721 + 26.7⊙	$P.C._1$	6° R.	2 24	Vernier = 4° 48′ for B. S. (= $I°$ − 2° 24′)
.75			1 21	(These settings for B. S.
.5			0 36	give 0° on the tang. for
.25			0 09	P.C.$_1$ and $I°$ on
+ 86.7⊙	$P.T.C.$			the tang. for P.T.C.$_1$.)
718		S. 18° W.		

12. Tangent Distance with Unequal Offsets.—From Fig. 5,

$$\left.\begin{aligned} T' &= T + AH - BJ \\ &= T + \frac{F'''}{\sin \Delta} - \frac{F'}{\tan \Delta} \\ &= R \tan \frac{\Delta}{2} + \frac{F'''}{\sin \Delta} - \frac{F'}{\tan \Delta}. \end{aligned}\right\} \quad . \quad . \quad . \quad (24)$$

$$\left.\begin{aligned} T'' &= T + BH - GH \\ &= T + \frac{F'}{\sin \Delta} - \frac{F''}{\tan \Delta} \\ &= R \tan \frac{\Delta}{2} + \frac{F'}{\sin \Delta} - \frac{F''}{\tan \Delta} \end{aligned}\right\} \quad . \quad . \quad . \quad (25)$$

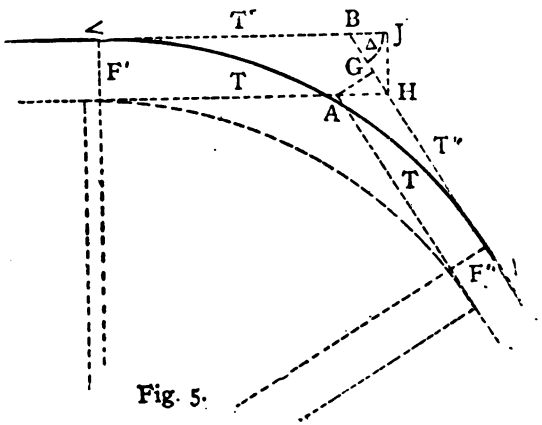


Fig. 5.

EXAMPLE 1. Compute the data for a 4° curve; $P.I.$ = sta. 51 + 35.6: $\Delta = 23° 15'$; $F' = 2.62$ ft.; $F'' = 0.94$ ft.

By (24), $$T' = 294.7 + \frac{0.94}{.3947} - \frac{2.62}{.4296} = 291.0.$$

(25), $$T'' = 294.7 + \frac{2.62}{.3947} - \frac{0.94}{.4296} = 299.2.$$

$$\text{Length of curve} = \frac{\Delta}{D} = 5\ 812 \text{ stas.}$$

$$\therefore P.C. = 51 + 44.6, \text{ with offset } F' = 2.62$$

$$P.T. = 57 + 25.8, \text{ with offset } F'' = 0.94.$$

No further attention need be given the transition curves, except to allow the proper offsets until track centers are required.

EX. 2. Write out the transit notes for Ex. 1 for track centers.

13. Transition Curve added without changing the Position of the Line opposite Vertex.— Let E be the external for the old curve, and E' that for the new. In Fig. 6,

$$PN = BN - BP.$$

$$\therefore E' = E - F \sec \frac{\Delta}{2}. \quad . \quad . \quad . \quad . \quad . \quad (26)$$

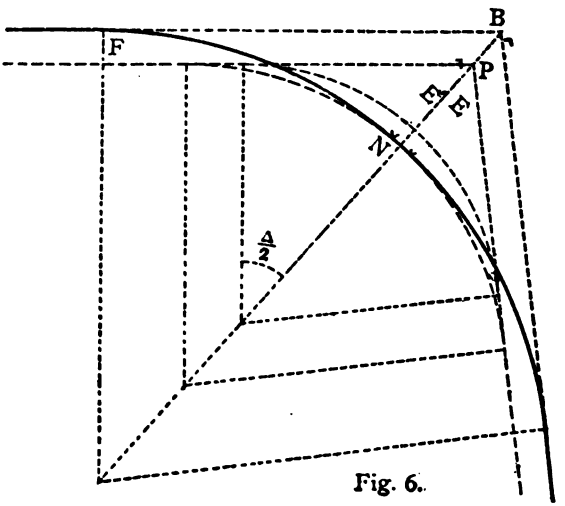


Fig. 6.

Divide the external distance for a 1° curve, Table VI, by D, for E, or compute it from $E = R\left(\sec \frac{\Delta}{2} - 1\right)$. Then find E' by (26), and divide the external for a 1° curve by it for D', the degree of the curve required.

D' can always be changed to the nearest whole minute for convenience in running without sensibly disturbing the required position.

It will be larger than D.

EXAMPLE 1. A 4° curve beginning at sta. 80 and ending at sta. 85 is to be replaced by a curve with a 1-ft. offset passing through the same point opposite the vertex.

Required the field-notes running the entire curves with a transit and using regular stas.

Table VI: for $\Delta = 20°$, external for 1° curve = 88.40, tangent = 1010.4.

$$\therefore E = 22.10,\ T = 252.6.$$

$$E' = 22.10 - \frac{1}{.985} = 21.08;$$

$$D' = \frac{88.40}{21.08} = 4° 11'.6, \text{ say } 4° 12';$$

$$T' = \frac{1010.4}{4.2} + .2 = 240.8.$$

Table I:

for $l_1 = 180$, $D = 4° 12'$; $F = .94 + \frac{18}{50}(1.18 - .94) = 0.99$;

$l_1 = 200$, $D = 4° 12'$; $F = 1.16 + \frac{18}{50}(1.45 - 1.16) = 1.22$.

$\therefore$ for $F = 1$, $D = 4° 12'$; $l_1 = 180 + 20\frac{1 - 0.99}{1.22 - 0.99} = 180\ 9$, $x' = 90.4$.

By (9), $I° = \frac{l_1 D}{200} = 3°.799$.

$$\text{Length of circular curve} = \frac{20 - 2 \times 3.799}{4.2} = 2.953 \text{ stas.}$$

$$P.T.C. = \text{sta. } 80 + T - T' - x' = 79 + 21.4.$$

The d's are interpolated from Table III.

TRANSIT NOTES.

Sta.	Point.	Vernier.	Remarks.
+ 78.5⊙	$P.T._1$	1° 16′	Vernier = 1° 16′ for backsight.
5		2 3.8	
4			
+ 97.6⊙	$P.T.C._1$	6 12	Vernier = 10° for backsight
3		4 9	(= $I°$ + 6° 12′).
2		2 3	
+ 2.3⊙	$P.C._1$	1 16	Vernier = 2° 32′ for backsight
1		1 13.8	(= $I°$ − 1° 16′).
80		0 14.4	
79 + 21.4⊙	$P.T.C.$		

14. Transition Curve added with the Least Deviation from the Old Roadbed, in improving Old Track.—For this case the new track should pass about as far outside opposite the vertex as it passes inside opposite the $P.C.$, or about $F + 2$.

$$\therefore E' = E - F \sec \frac{\Delta}{2} - \frac{F}{2}; \quad . \quad . \quad . \quad . \quad (27)$$

the problem otherwise being the same as § 13. Instead of $F + 2$, any other value can be used as desired.

15. Transition Curve added without changing the Length of the Track, to avoid cutting the Rails.—In Fig. 7, let A and H be the $P.C.$ and $P.T.$ for

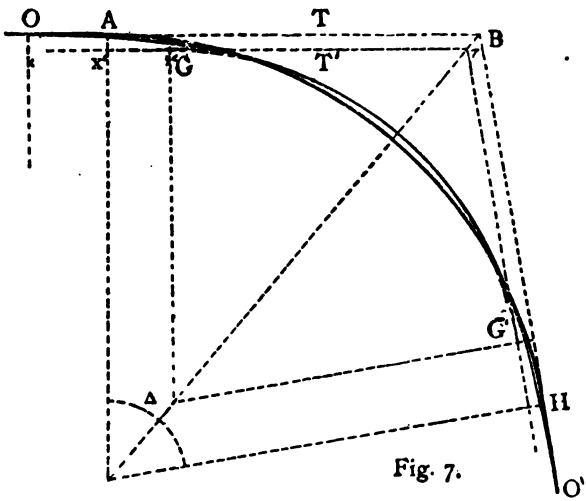


Fig. 7.

the old track; G and G' the $P.C.$ and $P.T.$, O and O' the $P.T.C.$ and $P.T._1$, for the new track.

By the old line,

$$\begin{aligned}\text{Dist. from } O \text{ to } O' &= OA + \text{arc } AH + HO' \\ &= 2OA + R\Delta \\ &= 2(T'' + x' - T) + R\Delta \\ &= 2\left((R' + F)\tan\frac{\Delta}{2} + x' - R\tan\frac{\Delta}{2}\right) + R\Delta;\end{aligned}$$

where Δ is in π-measure $= .017453\Delta°$.

By the new line,

$$\begin{aligned}\text{Dist. from } O \text{ to } O' &= 2(x' + e + e') + \text{arc } GG' \\ &= 2(x' + e + e') + R'\Delta;\end{aligned}$$

where x' and $e + e'$ are taken from Table I.

Placing the two values equal,

$$R'\Delta + 2(x' + e + e') = 2\left((R' + F)\tan\frac{\Delta}{2} + x' - R\tan\frac{\Delta}{2}\right) + R\Delta;$$

$$R' = \frac{.01745R\Delta^\circ - 2(R - F)\tan\frac{\Delta}{2} - 2(e + e')}{.01745\Delta^\circ - 2\tan\frac{\Delta}{2}}; \quad . \quad . \quad . \quad (28)$$

or

$$F = \frac{.008725(R' - R)\Delta^\circ + (e + e') + (R - R')\tan\frac{\Delta}{2}}{\tan\frac{\Delta}{2}}. \quad (29)$$

This problem is usually limited to small values of F or to small changes in R, so that $e + e'$ is practically known. For larger changes a second trial may be necessary.

EXAMPLE 1. Track has been laid on a 5° curve 900′ long. Required the data for transition curves without changing the length of the rails. Assume $F = 1.5$ ft., as it will give by § 9 an easy transition without too great shift of track.

Table I; $e + e' = 0$. Also, $\Delta = 45°$; $R = 5730 \div 5 = 1146$.

$$(28),\ R' = \frac{899.90 - 948.18 - .00}{.78525 - .82842} = 1117 \text{ ft.}$$

Changing R' to 1116.2 ft.,

$$D' = 5° 08'; \ L' = 45 \div 5.133 = 8.767 \text{ stas.}; \ T' = (1116.2 + 1.5)\tan\frac{\Delta}{2} = 463.0;$$

T for old curve = 474.7, requiring the $P.C.$ to be moved forward 11.7 ft.

Table I; by interpolation $l_1 = 200.7$ ft.

With stakes 100′ apart up to 8° curves, it is unnecessary to run the transition curve with an instrument; $y'(= F + 2$ in this case) locating a point opposite $P.C.$; x' measured back on the tangent locating $P.T.C.$, and $I_1 = l_1 D \div 200$, locating the $P.C._1$, each being distant $l_1 \div 2$ from the $P.C.$ in this case.

16. Transition Curve added without disturbing the Central Portion of the Circular Curve. —To make room for a given offset F, the end of the circular curve must be sharpened by compounding, and to prevent too great a difference in curvature at the $P.C.C.$, the change ould be limited to, say, 1° to 2°, i.e., $D'° - D° < 2°$.

The two circular curves are tangent to each other at G, Fig. 8, and the angle between them increases directly with the distance. Hence the offset from one to the other must increase with the square of the distance so long as the angle can be taken proportional to its sine, and the distance can be taken the same by either curve.

At 100 feet from G,

$$\text{Offset} = 100 \sin \tfrac{1}{2}(D' - D) = 50 \sin 1° \, (D'° - D°)$$
$$= \tfrac{7}{8}(D'° - D°).$$

Hence at n stations from G,

$$\left.\begin{aligned} &\text{Offset} = \tfrac{7}{8} n^2 (D'° - D°), \text{* approximately, or,} \\ &F < \tfrac{1}{4} n^2, \text{ for } (D'° - D°) < 2°. \end{aligned}\right\} \quad . \quad . \quad (30)$$

From this approximate value of n assume a convenient Δ_1. Then in Fig. 8,

$$HE = AC - AH - CE,$$

or
$$R' = R - F - (R - R') \cos \Delta_1,$$

from which

$$R' = R - \frac{F}{1 - \cos \Delta_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

Having R', the transition curve can be put in as usual.

For flat curves and short transition curves the problem can be simplified as follows:

Assume the $P.C._1$ from 100 to 200 feet from the $P.C.$; measure the perpendicular distance y_1 to the tangent, and the angle I which the curve at the $P.C._1$ makes with the tangent. If the curve is regular and the $P.C.$ can be accurately found, y_1 and I can be computed from AG or n. The coefficients C and E of equations (4) and (6) can be found from Table II with I as argument, giving

$$l_1 = \frac{y_1}{C}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32)$$

$$x_1 = l_1 - l_1 E. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

* This formula is very convenient in location, in computing the change of curvature required for a given offset. When $D = 0$, it reduces to

$$F = \tfrac{1}{4} n^2 D,$$

the offset from a tangent to a circular curve.

Measure x_1 back on the tangent from the foot of the perpendicular at $P.C._1$ for the $P.T.C.$ One or two intermediate points can be located by coördinates computed by Table II; or the curve can be run with transit, computing the deflection angles by Table III, or taking them proportional to the square of the distance with the instrument at the $P.T.C.$, the last one being $I + 8$, which will give a check on the work.

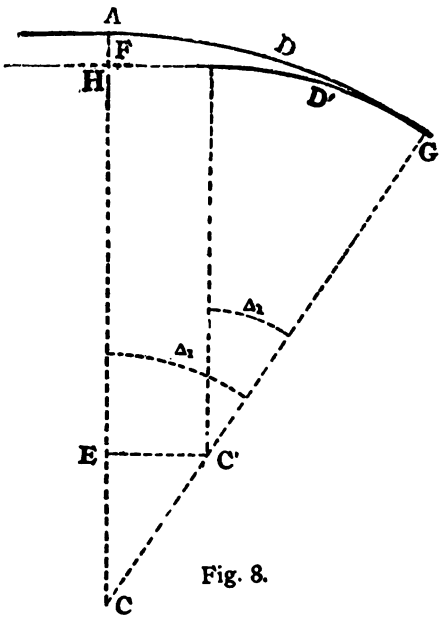


Fig. 8.

An approximate value of l_1 can be found from (82) by substituting the first term of the equation above (4) for C, giving

$$l_1 = \frac{3y_1}{.017453I^\circ}.$$

By the footnote to (30),

$$y_1 = \tfrac{1}{8}n'D.$$

Substituting,

$$l_1 = 150n^2 \frac{D}{I^\circ},$$

or

$$l_1 = 150n; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (34)$$

i.e., *the length of the transition curve is once and a half that of the circular curve from the P. C. to the P. C.*$_1$.

The degree of curvature at the *P. C.*$_1$ as found by (9) will be

$$D' = \frac{200I^\circ}{l_1};$$

by (34),

$$= \frac{200I^\circ}{150n} = \frac{200}{150}D,$$

or

$$D' = \tfrac{4}{3}D. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

The method is thus admissible to 3° curves if the break in curvature is limited to 1°, to 6° curves if the break is limited to 2°, etc., independently of the distance from the *P. C.* to the *P. C.*$_1$, or of the amount of the old track disturbed.

It can be extended to the case where there is an offset between the tangent and the circular curve at the *P. C.*, if desired; although it then offers no advantages over the regular methods already given, while it has the disadvantage of usually introducing a break in curvature at the *P. C.*$_1$. As the offset at the *P. C.* increases relatively to the offset y_1 at the *P. C.*$_1$, the break in curvature decreases, reaching zero when the ratio becomes 1 : 4; the transition curve having the flatter curvature ($D' < D$) at the *P. C.*$_1$ for all greater ratios.

EXAMPLE 1. Find the data for a 4-ft. offset for a long 13° curve without disturbing the central portion.

(30), $4 < \frac{3}{4}n^2$, giving $n > 1.51$.

Assume $\Delta_1 = 21°$, giving

(31), $R' = 477.5 - \dfrac{4}{1 - .91355} = 431.23.$

Table IV, $D' = 13° 17'$.

The *P. C.* will be moved forward, $= 200 - \dfrac{24}{D'}100 = 19.8$ ft.

Table I, with $F = 4$ ft., $D' = 13° 17'$; $l_1 = 203.7$; $x' = 101.6$; $I = \frac{l_1 D'}{200} = 13°.529$; $P.C.$ to $P.C._1 = l_1 + 2 = 101.8$.

The deflections can now be found from Table III, or the x and y coördinates from Table II.

By the second method; assume the $P.C._1$, say 100 feet on the curve; the $P.T.C.$ by (34) will be 50 feet back on the tangent; and the middle ordinate will be ½ that at $P.C._1$; the latter being readily measured on the ground, or it can be computed. The break in curvature at the $P.C._1$, however, will be by (35) $D' - D = \frac{1}{2} \times 12 - 12 = 4°$, as compared with 1° 17′ at the $P.C.C.$ by the first method. The former cannot be reduced, while the latter can be by diminishing F, or by increasing the distance from the $P.C.$ to the $P.C.C.$

17. Transition Curve added at the *P.C.C.* of a Compound Curve by changing the Degree of the Second Branch.—Draw a tangent $AB = T$ at the $P.C.C.$, Fig. 9, to meet the tangent at the $P.T.$ at B, and measure AB and Δ.

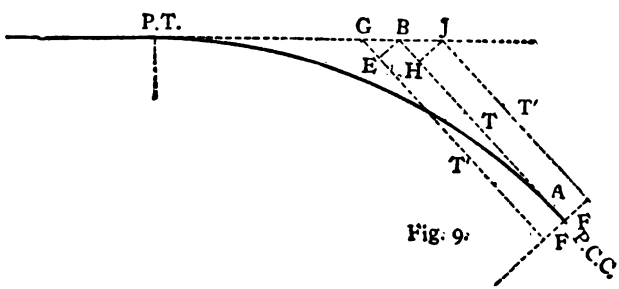


Fig. 9.

Let the required tangent be T'.

In the right triangles BJH and BEG,

$$GE = BH = F \cot \Delta.$$

$$\therefore T' = T \pm F \cot \Delta; \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$

where the plus sign is for the second branch sharper than the first, and the minus sign for the second branch flatter than the first.

To find D', divide the tangent for a 1° curve, Table VI, by T'', or

$$R' = T' \cot \frac{\Delta}{2}, \quad D' = \frac{5730}{R'}.$$

Having D', proceed as usual.

If an offset F' is added at the $P.T.$ also, T' will be shortened by $F' \div \sin \Delta$, giving

$$T'' = T \pm F \cot \Delta - \frac{F'}{\sin \Delta}, \quad . \quad . \quad . \quad . \quad (37)$$

with which proceed as above.

An offset is readily added at the $P.C.$ if desired, from what has already been given.

EXAMPLE 1. A 2C° curve compounds to a 12° at sta. 844, with the $P.T.$ at sta. 850.

Required the data for a 3-ft. offset at the $P.C.C.$ and a 7-ft. offset at the $P.T.$

$$\Delta = 72°; \ F = 3; \ F' = 7; \ T = R \tan \frac{\Delta}{2} = 346.9.$$

By (37), $T'' = 346.9 - 3 \times .325 - \frac{7}{.951} = 338.5.$

$$D'' = \frac{5730}{338.5 \times 1.37638} = 12°.3 = 12° 18'.$$

The new vertex comes opposite a point on the tangent back of the old by an amount

$$= \frac{F}{\sin \Delta} + F' \cot \Delta$$

$$= \frac{3}{.951} + 7 \times .325 = 5.4 \text{ ft.},$$

which places the new $P.T.$ back of the old an amount

$$= 5.4 + (346.9 - 338.5) = 13.8 \text{ ft.}$$

18. Transition Curve added at the *P.C.C.* of a Compound Curve by moving the *P.C.C.*

Let R_1 = the radius and C the center of the first branch; R_2 = the radius and C_1 the center of the second branch; Δ_2 = the central angle of the second branch; Δ'_2 = the required central angle with the offset F added at the $P.C.C.$; Δ''_2 = the required central angle with the offset F added at the $P.C.C.$ and F_2 at the $P.T.$

(*a*) $R_2 < R_1$ (Fig. 10).

With C as center and $R_1 - R_2 - F$ as radius, describe the arc GG' to meet a parallel to the tangent at $P.T.$ drawn

through the center C_1. G will be the new center required, and J the new $P.C.C.$

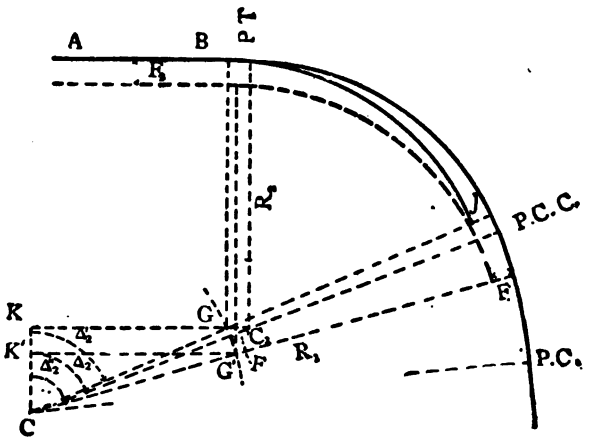
In the right triangle CC_1K,

$$CK = CC_1 \cos \Delta_2 = (R_1 - R_2) \cos \Delta_2.$$

In the right triangle CGK,

$$\cos \Delta'_2 = \frac{CK}{CG};$$

$$\cos \Delta'_2 = \frac{(R_1 - R_2) \cos \Delta_2}{R_1 - R_2 - F} \quad \ldots\ldots \quad (38)$$



With an offset F_2 at the $P.T.$, G' will be F_2 farther from AB than G, giving

$$\cos \Delta''_2 = \frac{CK'}{CG'};$$

$$\cos \Delta''_2 = \frac{(R_1 - R_2) \cos \Delta_2 - F_2}{R_1 - R_2 - F} \quad \ldots\ldots \quad (39)$$

(*b*). $R_2 > R_1$. (Fig. 11.)

$$CK = (R_2 - R_1) \cos \Delta_2;$$

$$\cos \Delta'_2 = \frac{(R_2 - R_1) \cos \Delta_2}{R_2 - R_1 - F} \quad \ldots\ldots \quad (40)$$

Or, with offset F_2 at $P.T.$,

$$\cos \Delta_2'' = \frac{(R_2 - R_1)\cos \Delta_2 + F_2}{R_2 - R_1 - F} \quad . \quad . \quad . \quad . \quad (41)$$

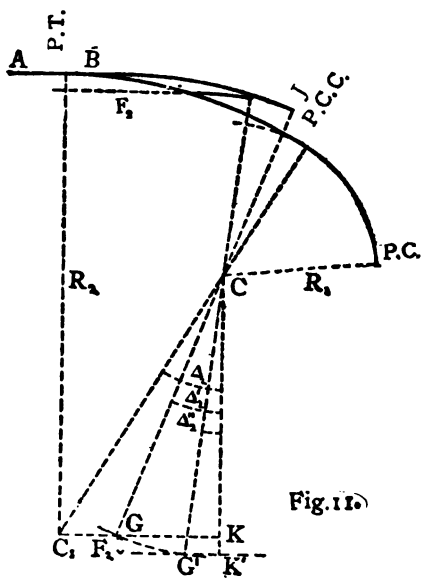


Fig. 11.

EXAMPLE 1. A 6° curve begins at sta. 672, compounds to an 18° at sta. 680, with a tangent at sta. 685. Required the data for an offset of 5.01 ft. at the $P.C.C.$, and 32 ft. at the $P.T.$

$$\Delta_2 = 90°;\ F = 5.01;\ F_2 = 32 \text{ ft.}$$

(39), $$\cos \Delta''_2 = \frac{(955 - 318.33)0 - 32}{955 - 318.33 - 5.01};$$

giving $\Delta''_2 = 92° 54'$.

$$\therefore P.C.C. = 680 + \frac{\Delta_2 - \Delta''_2}{D_1} = 679 + 51.7;$$

$$P.T. = 679 + 51.7 + \frac{\Delta''_2}{D_2} + (e + e') = 684 + 68.0;$$

taking $e + e'$ from Table I, for $D = 12°$, $F = 5.01$.

The deflections for the transition curve with the instrument at the $P.C.C.$ would be computed as follows, using the notation of § 10 and Fig. 3.

Table I, for $D - D'' = 12°$, and $F = 5.01$, gives $l_2 = 240$.

$l_1 = 240\frac{1}{2} = 360$, requiring 10 36-ft. chords; $l'' = 360 - 240 = 120$.

$D = 18°$, $l_1 = 360$, gives $I = 33°.4$, $x' = 178.1$, $F + R = 16.76 + 318.33 = 335.09$.

$D'' = 6°$, $l'' = 120$, gives $I'' = 3°.6$, $x'' = 60$, $F'' + R'' = .63 + 955 = 955.63$.

(30), $$\tan i = \frac{178.1 - 60}{955.63 - 335.09}; \quad i = 10° 46'\tfrac{1}{2};$$

$$G''J' = P.C_2 \text{ to } P.C.C. = \frac{i - I''}{D''} 100 = 119.6;$$

$$E''G'' = P.T.'' \text{ to } P.C._2 = \frac{I''}{D''} 100 = 60;$$

$$E'G = P.C.C. \text{ to } P.T.C._2 = \frac{I - i}{D} 100 = 120.1.$$

Table III. $d_0{}^{.1} = .01 \times 10°.8 = 0° 6\tfrac{1}{2}'$;

. . . . . .

$d_0{}^{\frac{1}{3}} = \frac{1}{3} \times 10\ 8 = 1\ 12 = P.C._2$;

. . . . . .

$d_0{}^1 = 1 \times 10.8 - .080 = 10\ 46 = P.T.C._2$.

∴ set up at E'' at sta. $679 + 51.7 - 119.6 - 60 = 677 + 72.1$, turn tangent; measure $x'' = 60$ back; offset $F'' = .63$, giving O; set up at O and run transition curve with above deflections and 36-ft. chords, except when interpolating $d_0{}^{\frac{1}{3}}$.

19. Old Track.—The problems already given will suffice for all the ordinary cases in aligning old track, where the curves are short and the tangents can be run to intersect at the *P.I.*, or can be connected across by a single tie-line.

With long sharp curves, where the roadbed usually lies in a deep cut or high fill, so that it is inconvenient to prolong the tangents to intersect, other methods will be found more desirable. On account of the trackman's habit of springing the tangent points in, making a sort of transition curve in his effort to secure an easy-riding track, the degree of curve can best be found by setting up on the central portion, and noting the deflections per station each way from the instrument. A value can then be assumed, and a trial-line extended through in each direction, noting distances from the center of the track at different points, and especially at the ends, in order to determine the offsets to the tangents.

The change in deflection, when small, required to pass the line through any given point can be found from (30),

$$\text{Offset} = \tfrac{1}{8}n^2(D' - D) = \tfrac{1}{4}n^2(d' - d);^*$$

where n = distance in stations, D and d the trial degree of curve and deflection, respectively, and D' and d' the required ones.

The change in the position of the first instrument point with reference to the center line, and the deflections which will best fit the roadbed, can thus be readily found. Slight changes in deflection, starting at instrument points, are admissible in order to lessen the shift of the track, the effect being to slightly compound the curve; while any slight discrepancy in the work can be thrown into the offset at the tangent and taken care of in the transition curve.

If in thus fitting the roadbed a suitable offset cannot be secured for the transition curve without too great expense for track-work, the end may be compounded by one of the methods of § 16. If the track is shifted more than, say, 2 feet, the estimated cost of track-work should include the extra cost of maintenance, due to the settlement of the ends of the ties on the new roadbed.

If the original curve is compound, the *P.C.C.* will be difficult to find directly with accuracy, owing to the approximate transition curve introduced by the trackman. In running the trial-line which fits the first branch of the compound curve, the distances from the center of the track will begin to increase in passing onto the second branch. Measuring two of these and substituting in (30),

$$\text{Offset} = \tfrac{1}{8}n^2(D' - D);$$
$$\text{Offset}' = \tfrac{1}{8}(n+1)^2(D' - D);$$

from which to find n and D', the other quantities being known. Or, D' can be found directly in the same manner as D, when one measured offset will give n, or the distance from the offset to the *P.C.C.*

Having the *P.C.C.*, if the change in curvature is great a transition curve can be added by the methods given in §§ 17, 18. Or a short transition curve can be added without chang-

* Searles's *Field Engineering*, Table X and §§ 146–152, on the valvoid curve, will give more accurate results, but with more labor.

ing the main portion of either branch of the compound curve by sharpening the sharp curve, and flattening the flat one by say 1°, for a distance n from the $P.C.C.$, so that the two changes will give the desired offset by (30). The curvature on one side will thus be increased as much as it is flattened on the other, leaving the two branches parallel at the $P.C.C.$, and at the offset distance apart. The transition curve can then be run by § 10; or, with a close approximation for short transition curves, by taking the ordinates starting from the $P.T.C._2$, or from the $P.C._2$, proportional to the cubes of the distances, that at the $P.C.C.$ being one half the offset. Or by the method in use with the Holbrook spirals; set up at the $P.C._2$, and measure the angle between the tangent at that point and the line to the $P.T.C._2$; take out the deflection corresponding to the flat curve for the entire distance, and assume the remainder to be due to the transition curve; intermediate deflections to be made up of the flat curve deflection proportional to distance, and the transition curve deflection proportional to the square of the distance.

Monuments should be placed at each end of each transition curve, so that the trackman may know where to begin his curvature and elevation of outer rail, and where to reach the full values required for the circular curve.

20. General Case.—The transition curve adds materially to the flexibility of the alignment, as already indicated.

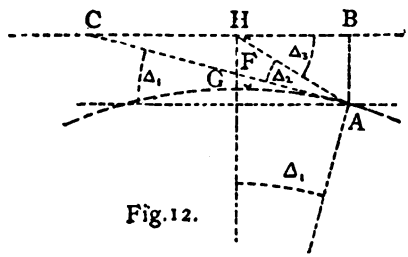


Fig. 12.

It also simplifies the field-work during location on crooked alignment by allowing, after the line has been fairly well fitted to the ground, any tangent or any curve to be studied by itself and shifted within the limits of the offsets if its position can be improved thereby. Many of the complicated field

problems can be simplified by running trial solutions; it often being easy to bring the last curve within the range of offsets of the tangent, and then use a transition curve. To find the *P.T.* and offset *F* between a circle and tangent which do not quite intersect or touch:

Run the curve to a convenient point *A*, Fig. 12, where it is approximately parallel to the given tangent; set up the instrument and measure the angle Δ_1 between the tangent proper and a parallel to the given tangent; also measure the perpendicular *AB*.

$$\text{Dist. to } P.T. = AG = \frac{\Delta_1}{D}.$$

$$\text{Offset } F = AB - AG \sin \frac{\Delta_1}{2}.$$

Or, sight from any point *A* near the *P.T.* to any point *H* on the tangent, and measure the angle Δ_2 between this line and the tangent proper at *A*; set up at *H* and measure the angle Δ_3 between this line and the given tangent; also measure the distance *AH*.

$$\Delta_1 = \Delta_3 \pm \Delta_2,$$

$$AB = AH \sin \Delta_3;$$

giving the same data as above.

EXAMPLE 1. A tangent joins a 6° curve to the left at the *P.T.* at sta. 824, and a 20° curve to the right at the *P.C.* at sta. 831. If the tangent be moved 3 ft. to the right at sta. 824, and 48.5 ft. to the left at sta. 831, to better fit the ground, find the data required.

Each central angle will be increased by $\tan^{-1} \frac{3 + 48.5}{700} = 4° 12\frac{1}{2}'$, lengthening the 6° curve by 70.1 ft., and the 20° curve by 21 ft.

The first offset $F = (R + 3) \cos 4° 12\frac{1}{2}' - R = 0.42.$

The second offset $F' = (R' + 48.5) \cos 4° 12\frac{1}{2}' - R' = 47.60.$

The length of the new tangent is best found when restaking it; it can be readily computed if desired.

21. Description of Right of Way.—The ordinary description for right of way calls for a given width each side of the center line, and then describes the center line as being so many feet along a tangent of a certain bearing, then along a curve of given degree, etc.

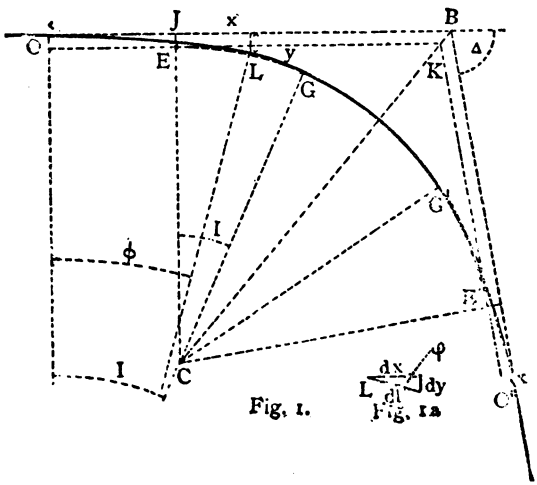
When a transition curve is added, it will be sufficient in describing the center line to note the offset thus: "Thence

along a tangent N. 20° W. from sta. 1081 to sta. 1086 + 50, a distance of 550 feet; thence along a 6° curve to the right to sta. 1091, a distance of 450 feet; thence along a tangent N. 7° E. to sta. 1102, a distance of 1100 feet, there being an offset of 0.4 feet at the beginning of the curve, and one of 0.5 feet at the end for a transition curve to connect the circular curve and tangent." The variation in transition curve for a given offset not being sufficient to seriously affect right-of-way lines.

FORMULAS.

(9), $I^\circ = \frac{l_1 D}{200} = 28.65 \frac{l_1}{R}$

$\phi^\circ = n^2 I^\circ$.



(4), $y = lC$; C from Table II, ϕ° as argument.

(6), $x = l - lE$; E from Table II, ϕ° as argument.

(5)-(10), x_1, y_1, F, x', y', e, e', $l' = x' + e$, see Table I.

(14)-(17), $d = \frac{I}{3}A - B$; A and B from Table III, n'', n, I° as arguments.

$$P.C. \text{ to } P.C._2 \text{ (circular arc)} = \frac{I}{D}100 = \frac{l_1}{2}.$$

COMPOUND CURVES.

(18), $l'' = l_1 \frac{D''}{D}$.

$$l_2 = l_1 - l'' = l_1 \frac{D - D''}{D}.$$

(19), $I'' = \frac{l'' D''}{200} = I \left(\frac{l''}{l_1}\right)^2$

(20), $\tan i = \frac{x' - x''}{F'' + R'' - F - R}$

$P.T.C._2$ to $P.C.C.$ (circular arc) $= \frac{I - i}{D} 100.$

$P.C.C.$ to $P.C._2$ (circular arc) $= \frac{i - I''}{D''} 100.$

TABLES.

Table I.

l_1 = length of transition curve, § 8;

$I°$ = central angle of transition curve from $P.T.C.$ to $P.C._1$, (9);

= central angle of circular curve from $P.C.$ to $P.C._1$;

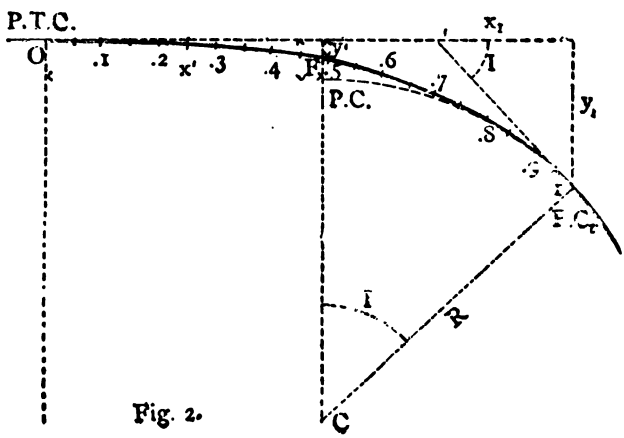


Fig. 2.

x_1, y_1, = coördinates of $P.C._1$ (3)–(6);
x', y', = coördinates of point opposite $P.C.$, (11);
F = offset from tangent to circular curve at $P.C.$, (11);
$l' = x' + e$ = length of transition curve from $P.T.C.$ to $P.C.$;
$e = l' - x'$ = excess of transition curve over tangent from $P.T.C.$ to $P.C.$;
$e' = \frac{l_1}{2} - l'$ — arc excess = excess of transition curve over circular curve from $P.C.$ to $P.C._1$, § 6.

Table II.

$\phi^\circ = n^2 I^\circ$ = central angle of transition curve from $P.T.C.$ to point distant l from $P.T.C.$, where $n = \frac{l}{l_1}$;
y = ordinate at any point from tangent at $P.T.C.$;
x = abscissa at any point measured along tangent at $P.T.C.$

Table III.

n, ϕ, as above;
n'' = instrument point;
d = deflection angle from tangent at $P.T.C.$, in degrees, for all values of I° from 0° to 60°, and for five values of n''. I° is taken from Table I.

Table IV.

Radii found by dividing 5730 by D.
Deflection angles in minutes per foot of length of curve.

Table V.

Actual circular arcs for a 100-foot chord, or for 100 feet measured along the chords.

Table VI.

Tangents and externals for a 1° curve with radius = 5730.

All tables computed on the basis that $R = \frac{5730}{D}$, requiring 100-foot chords to be used up to 8° curve, 50-foot chords from 8° to 16° curves, 25-foot chords from 16° to 32°, and 10-foot chords for all sharper curves.

FORM FOR PRESERVING DEFLECTIONS MOST COMMONLY USED.

Deflections for 2° curve; $I = 1°\ 30'$; $l_1 = 150$ ft.; $F = .32$ ft.

n	⊙ at Sta. 0.	⊙ at Sta. 1.	⊙ at Sta. .5.
0	0° 0′	0° 30′	
.1			
.2			
.3			
.4			
.5	0 7½	0 52½	
.6			
.7			
.8			
.9			
1	0 30	1 30	

Deflections for 7° curve; $I = 10°.50$; $l_1 = 300$ ft.; $F = 4.57$ ft.

n	⊙ at Sta. 0.	⊙ at Sta. 1.	⊙ at Sta. .5.
0	0° 0′		0° 52½′
.1			
.2			
.25	0 13		1 32
.3			
.4			
.5	0 52½	6° 7½′	2 37½
.6			
.7			
.75	1 58		4 09½
.8			
.9			
1	3 30	10 30	6 07½

Deflections for 20° curve; $I = 60°$; $l_1 = 600$ ft.; $F = 50.33$ ft.

n	⊙ at Sta. 0.	⊙ at Sta. .75.	⊙ at Sta. 1
0	0° 0′	11° 18′	
.05	0 3	12 01	
.1	0 12	12 55½	
.15	0 27	13 56	
.2	0 48	15 02	
.25	1 15	16 14	
.3	1 48	17 32½	
.35	2 27	18 57	
.4	3 12	20 27	
.45	4 03	22 03	
.5	5 00	23 45	
.55	6 03	25 33	
.6	7 11½	27 27	
.65	8 26	29 27	
.7	9 47	31 33	
.75	11 13	33 45	46° 15′
.8	12 45	36 03	
.85	14 23	38 27	
.9	16 06	40 57	
.95	17 55	43 33	
1	19 48½	46 15	60 00

TABLE I.

l_1	2° Curve.								3° Curve.								l_1
	I°	x_1	y_1	e	e'	F	x'	y'	I°	x_1	y_1	e	e'	F	x'	y'	
40	.40	40	.09			.02	20	.01	.60	40	.13			.03	20	.02	40
60	.60	60	.21			5	30	3	.90	60	.31			8	30	4	60
80	.80	80	.37			9	40	5	1.20	80	.56			.14	40	7	80
100	1.00	100	.58			.14	50	7	1.50	100	.88			.22	50	.11	100
120	1.20	120	.84			.21	60	.10	1.80	120	1.26			.32	60	.16	120
140	1.40	140	1.14			.28	70	.14	2.10	140	1.71			.43	70	.21	140
160	1.60	160	1.49			.37	80	.19	2.40	160	2.23			.56	80	.28	160
180	1.80	180	1.89			.47	90	.24	2.70	180	2.82		.01	.71	90	.35	180
200	2.00	200	2.33			.58	100	.29	3.00	200	3.49		1	.87	100	.44	200
220	2.20	220	2.84			.70	110	.35	3.30	220	4.23		1	1.06	110	.53	220
240	2.40	240	3.35			.84	120	.42	3.60	239.9	5.03		1	1.26	120	.63	240
260	2.60	259.9	3.93		.01	.98	130	.49	3.90	259.9	5.90		2	1.48	130	.74	260
280	2.80	279.9	4.56		1	1.14	140	.57	4.20	279.8	6.84		2	1.71	140	.86	280
300	3.00	299.9	5.24		1	1.31	150	.65	4.50	299.8	7.85	.01	2	1.96	150	.98	300
320	3.20	319.9	5.96		2	1.49	160	.74	4.80	319.7	8.93	1	2	2.23	160	1.12	320
340	3.40	339.9	6.73		2	1.68	170	.84	5.10	339.7	10.08	1	3	2.52	170	1.26	340
360	3.60	359.9	7.54		2	1.88	180	.94	5.40	359.7	11.30	1	3	2.83	179.9	1.41	360
380	3.80	379.8	8.40	.01	2	2.10	190	1.05	5.70	379.6	12.59	1	4	3.15	189.9	1.57	380
400	4.00	399.8	9.30	1	3	2.32	200	1.16	6.00	399.6	13.95	1	5	3.49	199.9	1.74	400
420	4.20	419.8	10.25	1	4	2.56	210	1.28	6.30	419.5	15.38	2	7	3.85	209.9	1.92	420
440	4.40	439.7	11.26	1	4	2.81	219.9	1.41	6.60	439.4	16.88	2	8	4.22	219.9	2.11	440
460	4.60	459.7	12.31	1	4	3.08	229.9	1.54	6.90	459.4	18.45	2	9	4.61	229.9	2.31	460
480	4.80	479.7	13.40	1	5	3.35	239.9	1.68	7.20	479.3	20.08	2	.10	5.02	239.9	2.51	480
500	5.00	499.6	14.54	1	6	3.63	249.9	1.82	7.50	499.2	21.78	3	.11	5.45	249.9	2.72	500
520	5.20	519.6	15.72	1	7	3.93	259.9	1.96	7.80	519.0	23.56	3	.12	5.89	259.8	2.94	520
540	5.40	539.5	16.95	2	7	4.24	269.9	2.12	8.10	538.9	25.41	3	.14	6.35	269.8	3.18	540
560	5.60	559.5	18.23	2	8	4.56	279.9	2.28	8.40	558.8	27.32	4	.16	6.83	279.8	3.42	560
580	5.80	579.4	19.56	2	9	4.89	289.9	2.44	8.70	578.7	29.30	4	.18	7.33	289.8	3.66	580
600	6.00	599.3	20.93	2	9	5.23	299.9	2.61	9.00	598.5	31.36	5	.20	7.84	299.7	3.92	600
620	6.20	619.3	22.35	2	.10	5.59	309.9	2.79	9.30	618.4	33.48	6	.22	8.37	309.7	4.19	620
640	6.40	639.2	23.81	2	.11	5.95	319.8	2.97	9.60	638.2	35.67	6	.24	8.92	319.7	4.46	640
660	6.60	659.1	25.32	3	.12	6.33	329.8	3.16	9.90	658.0	37.93	6	.27	9.48	329.6	4.74	660
680	6.80	679.0	26.87	3	.13	6.72	339.8	3.36	10.20	677.8	40.26	7	.30	10.07	339.6	5.03	680
700	7.00	699.0	28.47	4	.14	7.12	349.8	3.56	10.50	697.6	42.66	7	.33	10.67	349.5	5.33	700

TABLE I.

l_1	4° Curve.								5° Curve.								l_1
	$I°$	x_1	y_1	e	e'	F	x'	y'	$I°$	x_1	y_1	e	e'	F	x'	y'	
40	0.80	40	.18			.04	20	.02	1.00	40	.23		−.01	.06	20	.03	40
60	1.20	60	.42			.10	30	5	1.50	60	.52		1	.13	30	6	60
80	1.60	80	.74			.18	40	9	2.00	80	.93		1	.23	40	.12	80
100	2.00	100	1.16			.29	50	.14	2.50	100	1.45		1	.36	50	.18	100
120	2.40	120	1.67			.42	60	.21	3.00	120	2.09		1	.52	60	.26	120
140	2.80	140	2.28			.57	70	.28	3.50	140	2.85		1	.71	70	.36	140
160	3.20	160	2.98			.75	80	.37	4.00	159.9	3.72		−.01	.93	80	.47	160
180	3.60	179.9	3.77		.01	.94	90	.47	4.50	179.9	4.71			1.18	90	.59	180
200	4.00	199.9	4.65		1	1.16	100	.58	5.00	199.8	5.81			1.45	100	.73	200
220	4 40	219.9	5.62		1	1.41	110	.70	5.50	219.8	7.03	.01		1.76	110	.88	220
240	4.80	239.8	6.69	.01	2	1.67	120	.84	6 00	239.7	8.37	1	+.01	2.09	119.9	1.05	240
260	5.20	259.8	7.85	1	2	1.96	130	.98	6.50	259.7	9.82	1	1	2.46	129.9	1.23	260
280	5.60	279.7	9.11	1	3	2.28	139.9	1.14	7.00	279.6	11.39	1	2	2.85	139.9	1.42	280
300	6.00	299.7	10.46	1	3	2.62	149.9	1.31	7.50	299.5	13.07	2	3	3.27	149.9	1.63	300
320	6.40	319.6	11.90	1	4	2.98	159.9	1.49	8.00	319.4	14.87	2	5	3.72	159.9	1.86	320
340	6.80	339.5	13.43	1	5	3.36	169.9	1.68	8.50	339.3	16.78	2	6	4.20	169.9	2.10	340
360	7.20	359.4	15.06	2	6	3.77	179.9	1.88	9.00	359.1	18.81	3	8	4.70	179.8	2.35	360
380	7.60	379.3	16.78	2	7	4.20	189.9	2.10	9.50	379.0	20.96	3	.10	5.24	189.8	2.62	380
400	8.00	399.2	18.59	2	9	4.65	199.9	2.32	10.00	398.8	23.22	3	.12	5.81	199.8	2.90	400
420	8.40	419.1	20.49	3	.11	5.12	209.8	2.56	10.50	418.6	25.59	4	.2	6.40	209.7	3.20	420
440	8.80	439.0	22.49	3	.14	5.62	219.8	2.81	11.00	438.4	28.08	5	.2	7.03	219.7	3.51	440
460	9.20	458.9	24.58	3	.15	6.15	229.8	3.07	11.50	458.1	30.69	6	.2	7.68	229.7	3.83	460
480	9.60	478.7	26.75	4	.17	6.69	239.8	3.34	12.00	477.9	33.40	7	.3	8.36	239.6	4.17	480
500	10.00	498.5	29.02	5	.20	7.26	249.7	3.63	12.50	497.7	36.23	7	.3	9.07	249.6	4.53	500
520	10.40	518.3	31.38	6	.23	7.85	259.7	3.92	13.00	517.3	39.18	8	.4	9.81	259.5	4.90	520
540	10.80	538.1	33.84	6	.25	8.47	269.6	4 23	13.50	537.0	42.24	9	.4	10.58	269.5	5.28	540
560	11.20	557.9	36.39	7	.26	9.11	279.6	4.55	14.00	556.7	45.41	.1	.4	11.37	279.4	5.67	560
580	11.60	577.6	39.03	7	.29	9.77	289.6	4.88	14.50	576.3	48.70	.1	.5	12.20	289.3	6.08	580
600	12.00	597.4	41.75	8	.32	10.45	299.5	5.22	15.00	595.9	52.10	.1	.5	13.05	299.3	6.51	600
620	12.40	617.1	44.57	9	.36	11.15	309.5	5.57	15 50	615.4	55.61	.1	.6	13.93	309.2	6.95	620
640	12.80	636.8	47.48	.1	.4	11.88	319.4	5.93	16.00	635.0	59.24	.2	.6	14.85	319.1	7.39	640
660	13.20	656.5	50.48	.1	.5	12.64	329.4	6.30	16.50	654.5	62.98	.2	.7	15.79	329.0	7.86	660
680	13.60	676.2	53.58	.1	.5	13.42	339.3	6.69	17.00	674.0	66.83	.2	.7	16.76	339.0	8.34	680
700	14 00	695.8	56.77	.1	.6	14.22	349.2	7.08	17.50	693.5	70.79	.2	.8	17.75	348.9	8.84	700

TABLE I.

l_1	6° Curve.							7° Curve.							l_1
	$I°$	x_1	y_1	e	e'	F	x'	y'	$I°$	x_1	y_1	e	e'	F	x'	y'	
40	1.20	40	.28		−.01	.07	20	.03	1.40	40	.32		−.01	.08	20	.04	40
60	1 80	60	.63		1	.16	30	.08	2.10	60	.73		2	.18	30	.09	60
80	2.40	80	1.11		1	.28	40	.14	2.80	80	1.30		2	.33	40	.16	80
100	3.00	100	1.74		1	.44	50	.22	3.50	100	2.04		2	.51	50	.25	100
120	3.60	120	2.51		1	.63	60	.31	4.20	119.9	2.93		2	.73	60	.36	120
140	4.20	139.9	3 42		1	.86	70	.43	4.90	139.9	3.99		2	1.00	70	.50	140
160	4.80	159.9	4 47		1	1.12	80	.56	5.60	159 8	5.21		2	1.30	80	.65	160
180	5 40	179.8	5 66		1	1.42	90	.71	6.30	179.8	6.59	.01	2	1.65	90	.82	180
200	6.00	199.8	6.98	.01	−.01	1.75	100	.87	7.00	199.7	8.14	1	−.01	2.04	99.9	1.02	200
220	6 60	219.7	8.44	1		2.11	109.9	1.05	7.70	219.6	9.85	1		2.46	109.9	1.23	220
240	7.20	239.6	10.04	1	+.01	2.51	119.9	1.25	8.40	239.5	11.72	2		2.93	119.9	1.46	240
260	7.80	259.5	11.78	1	2	2.95	129.9	1.47	9.10	259.4	13 75	2	+.01	3.44	129.9	1.72	260
280	8.40	279.4	13.66	2	3	3.42	139.9	1.71	9.80	279.2	15.93	3	1	3.99	139.9	1.99	280
300	9.00	299.3	15.68	2	4	3.92	149.9	1.96	10.50	299.0	18.28	3	4	4.57	149.8	2.28	300
320	9.60	319.1	17 83	3	6	4.46	159.8	2.23	11.20	318.8	20.79	4	8	5.20	159 8	2.60	320
340	10.20	338.9	20.12	3	8	5.03	169.8	2.52	11.90	338.5	23.46	5	.11	5.87	169.7	2.93	340
360	10.80	358.7	22.56	4	.11	5.64	179.8	2 82	12.60	358.3	26.29	5	.14	6.58	179.7	3.28	360
380	11.40	378.5	25.13	5	.14	6.28	189.7	3.14	13.30	378.0	29.28	6	.17	7.33	189.7	3.66	380
400	12.00	398.2	27.83	5	.18	6.96	199.7	3.48	14.00	397.6	32.43	7	.22	8.12	199.6	4.05	400
420	12.60	418.0	30.68	6	.2	7.68	209.7	3.83	14.70	417.2	35.74	9	.3	8.95	209.5	4.46	420
440	13.20	437.7	33.66	7	.2	8.43	219.6	4.20	15.40	436.8	39.21	.10	.4	9.82	219.4	4.89	440
460	13.80	457.3	36.78	8	.3	9.21	229.5	4.59	16.10	456.4	42.84	.11	.4	10.73	229.4	5.35	460
480	14.40	477.0	40.03	9	.3	10.03	239.5	5.00	16.80	475.9	46.62	.13	.4	11.68	239.3	5.82	480
500	15.00	496.7	43.42	.10	.4	10.88	249.4	5.42	17.50	495.4	50.56	.14	.5	12.67	249.2	6.31	500
520	15.60	516.2	46.94	.1	.5	11.76	259.3	5.86	18.20	514.8	54.66	.2	.5	13.70	259.1	6.82	520
540	16.20	535.7	50.60	.1	.5	12.68	269.2	6 32	18.90	534.2	58 91	.2	.6	14.78	269.0	7.35	540
560	16.80	555.2	54.39	.2	.5	13.63	279.2	6.79	19.60	553.5	63.32	.2	.7	15.89	278.9	7.90	560
580	17.40	574.7	58.32	.2	.6	14.62	289.1	7.28	20.30	572.8	67 88	.2	.8	17.04	288.8	8.47	580
600	18.00	594.1	62.38	.2	.8	15.64	299.0	7.79	21.00	592.0	72.60	.3	.9	18.23	298.6	9.06	600
620	18.60	613.5	66.58	.2	.9	16.70	308.9	8 31	21.70	611.2	77.47	.3	1.0	19.46	308.5	9.67	620
640	19.20	632.8	70.91	.2	1.0	17.79	318.7	8.85	22.40	630.3	82.49	.3	1.1	20.73	318.4	10.29	640
660	19.80	652.1	75.37	.2	1.0	18.91	328.6	9.40	23.10	649.4	87.67	.3	1.2	22.04	328.3	10.94	660
680	20.40	671.4	79.97	.3	1.1	20.07	338.5	9 97	23.80	668.4	93.00	.4	1.3	23.39	338.1	11.60	680
700	21.00	690.6	84.70	.3	1.1	21.27	348.4	10.56	24.50	687.3	98.48	.4	1.5	24.78	347.9	12.28	700

40	1.60	40	.37			.09	20	.05	1.80	40	.42			.11	20	.05	40
60	2.40	60	.84			.21	30	.11	2.70	60	.94			.24	30	.12	60
80	3.20	80	1.49			.37	40	.19	3.60	80	1.67			.42	40	.21	80
100	4.00	100	2.33			.58	50	.29	4.50	99.9	2.62			.66	50	.33	100
120	4.80	119.9	3.35			.84	60	.42	5.40	119.9	3.77		.01	.94	60	.47	120
140	5.60	139.9	4.56		.01	1.14	70	.57	6.30	139.8	5.13	.01	1	1.28	70	.64	140
160	6.40	159.8	5.95	.01	2	1.49	80	.74	7.20	159.7	6.70	1	2	1.68	80	.84	160
180	7.20	179.7	7.53	1	3	1.88	89.9	.94	8.10	179.6	8.47	1	3	2.12	89 9	1.06	180
200	8.00	199.6	9.29	1	4	2.32	99.9	1.16	9.00	199.5	10.45	2	4	2.61	99.9	1.30	200
220	8.80	219.5	11.24	2	6	2.81	109.9	1.40	9.90	219.3	12.64	2	6	3.16	109.9	1.58	220
240	9.60	239.3	13.38	2	7	3 35	119.9	1.67	10.80	239.2	15.04	3	9	3.76	119.9	1.88	240
260	10.40	259 1	15.70	3	.10	3.93	129.8	1.96	11.70	258.9	17.64	3	.12	4.42	129.8	2.20	260
280	11.20	278.9	18.20	3	.13	4.56	139.8	2.27	12.60	278.7	20.45	4	.16	5.12	139.8	2.55	280
300	12.00	298.7	20.88	4	.16	5.23	149.8	2.61	13.50	298.3	23.47	5	.20	5.88	149.7	2.93	300
320	12.80	318.4	23.74	5	.20	5.95	159.7	2.97	14.40	318.0	26.69	6	.24	6.69	159.7	3.33	320
340	13.60	338.1	26.79	6	.24	6.71	169.7	3.35	15.30	337.6	30.11	8	.30	7.55	169.6	3.76	340
360	14.40	357.7	30 02	7	.29	7.52	179.6	3.75	16.20	357.1	33.73	9	.36	8.45	179.5	4.21	360
380	15 20	377.3	33.43	8	.34	8.37	189.5	4.17	17.10	376.6	37.56	.11	.43	9.41	189.4	4.69	380
400	16.00	396.9	37.02	.10	.41	9.27	199.5	4.62	18.00	396.1	41.59	.12	.51	10.43	199.3	5.19	400
420	16.80	416.4	40.79	.1	.5	10.22	209.4	5.09	18.90	415.4	45.82	.1	.6	11.49	209.2	5.72	420
440	17.60	435.9	44.74	.1	.6	11.21	219.3	5.58	19.80	434.7	50.25	.2	.6	12.61	219.1	6.27	440
460	18 40	455.3	48.87	.1	.7	12.25	229.2	6.10	20.70	454.0	54.88	.2	.7	13.78	229.0	6.84	460
480	19.20	474.6	53.18	2	.7	13.34	239.1	6.64	21.60	473.2	59.70	.2	.9	14.99	238.8	7.44	480
500	20.00	493.9	57.66	.2	.8	14.47	249.0	7.19	22.50	492.3	64.72	.2	1.0	16.26	248.7	8.07	500
520	20.80	513.2	62 32	.2	.9	15.64	258.8	7.77	23.40	511.4	69.94	.3	1.1	17.58	258.5	8.72	520
540	21.60	532.4	67.16	.2	1.0	16.86	268.7	8.37	24 30	530.4	75.35	.3	1.3	18.95	268.3	9.39	540
560	22.40	551.5	72.18	.3	1.0	18.13	278.6	9.00	25.20	549.2	80.96	.3	1.5	20.37	278.1	10.08	560
580	23.20	570.6	77.37	.3	1.2	19.45	288.4	9.65	26.10	568.0	86.76	.4	1.6	21.84	287.9	10.80	580
600	24.00	589.6	82.73	.3	1.4	20 81	298.2	10.31	27.00	586.7	92.75	.4	1 8	23.36	297.7	11.55	600
620	24.80	608.5	88.26	.4	1.4	22.21	308.1	11.00	27.90	605.3	98.93	.5	2.0	24.93	307.4	12.31	620
640	25 60	627 3	93.96	.4	1.6	23.66	317.9	11.71	28.80	624.0	105.30	.5	2.2	26.55	317 2	13.10	640
660	26.40	646.1	99.84	.4	1.9	25.15	327.6	12.44	29.70	642.5	111.86	.6	2.3	28.22	327.0	13.93	660
680	27.20	664.8	105.88	.5	2.0	26 68	337.4	13.19	30.60	660.9	118.60	.6	2.5	29.94	336.8	14.76	680
700	28.00	683.5	112.09	.5	2.2	28.25	347.2	13.96	31.50	679.1	125.53	.7	2.7	31.71	346.5	15.62	700

TABLE I.

l_1	10° Curve.								11° Curve.							l_1
	$I°$	x_1	y_1	e	e'	F	x'	y'	$I°$	x_1	y_1	e	e'	F	x'	y'	
40	2.00	40	.47			.12	20	.06	2.20	40	.51			.13	20	.06	40
60	3.00	60	1.05			.26	30	.13	3.30	60	1.15			.29	30	.14	60
80	4.00	80	1.86			.47	40	.23	4.40	80	2.05			.51	40	.26	80
100	5.00	99.9	2.91			.73	50	.36	5.50	99.9	3.20			.80	50	.40	100
120	6.00	119.9	4.19		.01	1.05	60	.52	6 60	119.8	4.60	.01		1.15	60	.57	120
140	7.00	139.8	5.70	.01	1	1.43	70	.71	7.70	139.7	6.25	1	.01	1.56	70	.78	140
160	8.00	159.7	7.44	1	2	1.86	79.9	93	8.80	159.6	8.16	1	3	2.04	79 9	1.02	160
180	9.00	179.6	9.41	1	4	2.36	89.9	1.18	9.90	179.5	10.33	1	5	2.58	89.9	1.29	180
200	10.00	199.4	11.61	2	6	2.91	99.9	1.45	11.00	199.3	12.75	2	7	3.19	99.9	1.59	200
220	11.00	219.2	14.04	3	8	3.51	109 9	1.75	12.10	219.0	15.43	3	.10	3.86	109.8	1.93	220
240	12.00	239.0	16.70	3	.11	4.18	119.8	2.09	13.20	238.7	18.36	4	.13	4.60	119.8	2.30	240
260	13.00	258.7	19.59	4	.15	4.90	129.8	2.45	14.30	258.4	21.54	5	.18	5.40	129.7	2.69	260
280	14.00	278.3	22.71	5	.19	5.68	139.7	2.84	15.40	278.0	24.96	6	.23	6.25	139 7	3.12	280
300	15.00	297.9	26.05	6	.24	6.52	149.7	3.26	16.50	297.5	28.63	8	.28	7.17	149.6	3.58	300
320	16 00	317.5	29.62	8	.29	7.42	159.6	3.70	17.60	317.0	32.55	.10	.35	8.15	159.5	4.07	320
340	17.00	337.0	33.41	9	.37	8.37	169.5	4.17	18.70	336.4	36.71	.11	.44	9.20	169.4	4.59	340
360	18.00	356.5	37.43	.11	.44	9.38	179.4	4.67	19.80	355.7	41.11	.13	.52	10.31	179.3	5.13	360
380	19 00	375.9	41.67	.13	.52	10.45	189.3	5.20	20.90	375.0	45.76	.15	.62	11 48	189.2	5.70	380
400	20.00	395.2	46.13	.15	.61	11.57	199.2	5.76	22.00	394.2	50.65	.18	.73	12.72	199.0	6.31	400
420	21.00	414.5	50.81	.2	.7	12.75	209.1	6.34	23.10	413.3	55.78	.2	.8	14.01	208.9	6.95	420
440	22.00	433.6	55.72	.2	.8	13.99	218.9	6.95	24.20	432.2	61.15	.2	1.0	15.37	218.7	7.62	440
460	23.00	452.6	60.84	.2	.9	15.29	228.7	7.59	25.30	451.1	66.76	.3	1.1	16.79	228.5	8.33	460
480	24.00	471.7	66.18	.3	1.1	16.64	238.6	8.25	26.40	469.9	72.61	.3	1.3	18.28	238.3	9.06	480
500	25.00	490.6	71.73	.3	1.2	18.05	248.4	8.94	27.50	488.6	78.69	.4	1.4	19.83	248.1	9.81	500
520	26.00	509.4	77.50	.3	1.3	19.51	258 2	9.66	28.60	507.2	85.00	.4	1.6	21.44	257.9	10.59	520
540	27.00	528.1	83.48	.4	1.5	21 03	268.0	10.40	29.70	525.7	91.53	.4	1.8	23.11	267.6	11.40	540
560	28.00	546.8	89.67	.4	1.7	22.60	277.8	11.17	30.80	544.1	98.29	.5	2.0	24.83	277.4	12.24	560
580	29.00	565.3	96.07	.5	2.0	24.23	287.5	11.97	31.90	562.4	105.27	.6	2.3	26.60	287.1	13.11	580
600	30.00	583.8	102.68	.5	2.2	25.91	297.3	12.79	33.00	580.5	112.48	.6	2.5	28.44	296.8	14.01	600
620	31.00	602.1	109.49	.6	2.4	27.64	307.0	13.64	34.10	598.5	119.91	.7	2.7	30.34	306.5	14.93	620
640	32.00	620.3	116.51	.6	2.6	29.44	316.7	14.51	35.20	616.4	127.56	.7	3.0	32.31	316 1	15.87	640
660	33.00	638.4	123.73	.7	2.9	31.29	326.4	15.40	36.30	634.1	135.43	.8	3.3	34.34	325.7	16.84	660
680	34.00	656.5	131.15	.7	3.2	33.19	336.0	16.31	37.40	651.7	143.51	.9	3.7	36.42	335.3	17.84	680
[illegible]	[illegible]	[illegible]	138.77	.8	3.4	35.14	346.7	17.25	38 50	669.2	151.79	.9	4.0	38.56	344.9	18.87	700

l_1	17° Curve.								18° Curve.							l_1
	I°	x_1	y_1	e	e'	F	x'	y'	I°	x_1	y_1	e	e'	F	x'	y'	
40	2.40	40	.56			.14	20	.07	2 60	40	.60			.15	20	.07	40
60	3.60	60	1.26			.32	30	.16	3.90	60	1.36			.34	30	.17	60
80	4.80	79.9	2.23			.56	40	.28	5.20	79.9	2.42			.61	40	.30	80
100	6.00	99.9	3.49			.87	50	.44	6.50	99.9	3.78			.95	50	.47	100
120	7.20	119.8	5.02	.01		1.26	60	.63	7.80	119.8	5.44	.01		1.36	60	.68	120
140	8.40	139.7	6.83	1	.01	1.71	69.9	.85	9.10	139.6	7.40	1	.02	1.85	69.9	.92	140
160	9.60	159.6	8.92	1	3	2.23	79.9	1.11	10.40	159.5	9.66	2	4	2.42	79.9	1.21	160
180	10.80	179.4	11.28	2	5	2.82	89 9	1.41	11.70	179.3	12.22	2	6	3.06	89.8	1.53	180
200	12.00	199.1	13.92	3	8	3.49	99 8	1.74	13.00	199.0	15.07	3	.10	3.77	99.8	1.88	200
220	13.20	218.8	16.83	4	.11	4.22	109.8	2.10	14.30	218.6	18.22	4	.13	4.56	109.8	2.28	220
240	14.40	238.5	20.01	5	.15	5.01	119 7	2.50	15.60	238.2	21.66	6	.18	5.42	119.7	2.71	240
260	15.60	258.1	23.47	6	.20	5.88	129.7	2.93	16.90	257.7	25.39	7	.24	6.36	129.6	3.17	260
280	16.80	277.6	27.20	8	.27	6.82	139.6	3.40	18.20	277.2	29.43	9	.31	7.38	139.5	3.68	280
300	18.00	297.0	31.20	9	.34	7.82	149.5	3.90	19.50	296.5	33 76	.11	.39	8.48	149.4	4.22	300
320	19.20	316.4	35.46	.11	.42	8.89	159.4	4.43	20.80	315.8	38.37	.13	.49	9.64	159.3	4.79	320
340	20.40	335.7	39.98	.13	.52	10.03	169.3	4.99	22 10	335.0	43.26	.16	.60	10.87	169.2	5.40	340
360	21.60	354.9	44.77	.15	.62	11.24	179.1	5.59	23.40	354.1	48.43	.19	.72	12.18	179.0	6.04	360
380	22.80	374.0	49 83	.18	.75	12.52	189.0	6.22	24.70	373 0	53.88	.22	.86	13.56	188.8	6.72	380
400	24.00	393.0	55.15	.21	.88	13.86	198.8	6.87	26.00	391.8	59.61	.25	1.03	15.01	198.6	7.43	400
420	25.20	411.9	60.73	.2	1.0	15.27	208.6	7.57	27.30	410.5	65 62	.3	1.2	16 53	208.4	8.18	420
440	26.40	430.8	66 56	.3	1.2	16.75	218.4	8.29	28.60	429.2	71.91	.3	1.4	18.13	218.2	8.96	440
460	27.60	449.4	72.64	.3	1.4	18.30	228.2	9.05	29.90	447.6	78.47	.4	1.6	19 80	227.9	9.77	460
480	28.80	468.0	78.98	.4	1.6	19.92	238.0	9.84	31.20	466.0	85.29	.4	1 8	21.54	237.6	10.62	480
500	30.00	486.4	85.57	.4	1.8	21.60	247.7	10.65	32.50	484 2	92.38	.5	2.1	23.35	247.3	11.50	500
520	31.20	504.8	92.40	.5	2.0	23.34	257.4	11.49	33.80	502.2	99 73	.5	2.3	25.28	257.0	12.41	520
540	32.40	523.0	99.48	.5	2 2	25.15	267.1	12.37	35.10	520.1	107.34	.6	2.6	27.18	266.7	13.35	540
560	33.60	541.0	106.80	.6	2 5	27.02	276.8	13.28	36.40	537.8	115.21	.7	2.9	29.21	276.3	14.32	560
580	34.80	559.0	114.36	.6	2.8	28.96	286.4	14.21	37.70	555.4	123.33	.7	3.2	31.31	285.9	15.32	580
600	36.00	576.8	122.16	.7	3.1	30.96	296.1	15.17	39.00	572.8	131.70	.8	3.6	33.47	295.4	16.35	600
620	37.20	594.4	130.19	.8	3 4	33.03	305.7	16.16	40.30	590.0	140.31	.9	4.0	35.70	304.9	17.41	620
640	38.40	611.9	138.45	.8	3.8	35.16	315.2	17.18	41.60	607.1	149.16	1 0	4.4	38.00	314 4	18.50	640
660	39.60	629.2	146.93	.9	4.1	37.35	324.8	18.23	42.90	624 0	158.23	1.1	4.8	40.36	323 9	19.62	660
680	40.80	646.3	155 64	1.0	4.5	39 60	334.3	19.30	44.20	640.6	167.56	1.2	5.3	42.79	333.3	20.77	680
700	42.00	663.3	164.58	1.1	5.0	41.92	343.8	20 40	45.50	657.1	177.11	1.3	5.8	45.28	342.8	21.95	700

TABLE I.

l_1	14° Curve.								16° Curve.								l_1
	$I°$	x_1	y_1	e	e'	F	x'	y'	$I°$	x_1	y_1	e	e'	F	x'	y'	
40	2.8	40	.65			.16	20	.08	3.2	40	.74			.19	20	.09	40
60	4 2	60	1.47			.37	30	.18	4.8	60	1.67			.42	30	.21	60
80	5 6	79.9	2 60			.65	40	.32	6.4	79.9	2.98			.75	40	.37	80
100	7.0	99 8	4.07			1.02	50	.51	8.0	99.8	4.65	.01	.02	1.16	50	.58	100
120	8.4	119.7	5.86	.01		1.47	60	.73	9.6	119.7	6.69	1	4	1.67	59.9	.83	120
140	9.8	139.6	7.97	1	.02	1.99	69 9	.99	11.2	139.5	9.10	2	7	2.27	69.9	1.13	140
160	11.2	159.4	10.40	2	4	2.60	79.9	1.30	12.8	159 2	11.87	2	.10	2.97	79.9	1.48	160
180	12.6	179.1	13.15	3	6	3.29	89.8	1.64	14.4	178.9	15.01	4	.14	3.76	89.8	1.87	180
200	14.0	198.8	16.22	4	.10	4.06	99.8	2.03	16.0	198 5	18.51	5	.20	4.64	99.7	2.31	200
220	15.4	218.4	19.61	5	.15	4.92	109.7	2.45	17.6	217.9	22 37	6	.27	5.61	109.7	2.79	220
240	16.8	237.9	23.31	6	.22	5.85	119.7	2 91	19.2	237.3	26.59	8	.35	6.68	119.5	3.32	240
260	18.2	257.4	27.33	8	.29	6.86	129.5	3.41	20.8	256.6	31.16	.10	.42	7.83	129.4	3.89	260
280	19.6	276.7	31.66	.11	.36	7.95	139.4	3.95	22.4	275.8	36.09	.13	.50	9.07	139.3	4.50	280
300	21.0	296.0	36.30	.13	.46	9.12	149.3	4.53	24.0	294.8	41.37	.16	.63	10.40	149.1	5.15	300
320	22.4	315.1	41.24	.2	.6	10.36	159.2	5.14	25.6	313.7	46.99	.2	.8	11.82	158.9	5.85	320
340	23.8	334.2	46.49	.2	.7	11.68	169.0	5.79	27.2	332.4	52.95	.2	1.0	13.33	168.7	6.59	340
360	25.2	353.1	52 04	.2	.8	13.09	178.8	6.48	28.8	351.0	59.24	.3	1.2	14.93	178.5	7.38	360
380	26.6	371.9	57.89	.2	1.0	14.58	188.6	7.21	30.4	369.4	65.86	.3	1.4	16.62	188.2	8.30	380
400	28.0	390.6	64.05	.3	1.2	16.14	198.4	7.98	32.0	387.7	72.82	.4	1.7	18 40	197.9	9.06	400
420	29.4	409.1	70 50	.3	1.4	17.78	208.2	8.78	33.6	405.8	80.10	.4	1.8	20.26	207.6	9.96	420
440	30.8	427.5	77.23	.4	1.6	19.50	217.9	9.62	35.2	423.7	87.70	.5	2.2	22.21	217.3	10.90	440
460	32.2	445.7	84.24	.4	1.8	21.29	227.6	10.49	36.8	441 4	95.61	.6	2.5	24.25	226 9	11.88	460
480	33.6	463.8	91.54	.5	2.1	23.16	237.3	11.39	38.4	458.9	103.84	.6	2.9	26.37	236.4	12 90	480
500	35.0	481.7	99.12	.6	2.4	25.11	246.9	12.32	40.0	476.2	112.37	.7	3.3	28.58	246.0	13.95	500
520	36.4	499.4	106.98	.6	2.7	27.13	256.5	13.29	41.6	493.3	121.19	.8	3.7	30.87	255.5	15.04	520
540	37.8	517.0	115.11	.7	3.0	29.22	266.1	14.29	43.2	510.1	130.30	.9	4.1	33.24	265.0	16.16	540
560	39 2	534.4	123.50	.8	3.4	31.39	275.7	15.33	44.8	526.7	139.70	1.0	4.6	35.69	274.4	17.32	560
580	40.6	551.6	132.15	.8	3.8	33.63	285.2	16.40	46.4	543.1	149.38	1.1	5.1	38.23	283.8	18.51	580
600	42.0	568.6	141.07	.9	4.2	35.94	294.7	17.50	48.0	559.2	159.33	1.2	5.6	40.84	293.1	19.72	600
620	43.4	585.4	150.24	1.0	4.6	38.33	304.2	18.63	49.6	575.1	169.55	1.3	6.2	43.53	302.4	20.96	620
640	44.8	602.0	159.66	1.1	5.1	40.79	313.6	19.79	51.2	590.8	180.03	1.4	6.8	46.30	311.7	22.24	640
660	46.2	618 4	169.32	1.3	5 5	43.32	323.0	20.97	52.8	606.1	190.76	1.6	7.4	49.15	320.9	23.55	660
680	47.6	634.6	179 22	1.4	6.1	45.92	332.3	22.18	54.4	621.2	201.73	1.7	8.2	52.08	330.0	24.89	680
700	49.0	650 5	189.35	1 5	6.7	48.58	341.6	23.42	56.0	636.0	212.95	1.8	9.0	55.09	339.1	26.25	700

TABLE I.

l_1	18° Curve.							20° Curve.							l_1
	$I°$	x_1	y_1	e	e'	F	x'	y'	$I°$	x_1	y_1	e	e'	F	x'	y'	
40	3.6	40	.84			.21	20	.10	4.0	40	.93			.23	20	.12	40
60	5.4	59.9	1.88			.47	30	.24	6.0	59.9	2.09			.52	30	.26	60
80	7.2	79.9	3.35			.84	40	.42	8.0	79.8	3.72		.01	.93	40	0.46	80
100	9.0	99.8	5.23	.01	.02	1.31	50	.65	10.0	99.7	5.81	.01	2	1.45	49.9	0.72	100
120	10.8	119.6	7.52	1	5	1.88	59.9	.94	12.0	119.5	8.35	2	6	2.09	59.9	1.04	120
140	12.6	139.3	10.22	2	8	2.56	69.9	1.28	14.0	139.2	11.35	3	.10	2.84	69.8	1.42	140
160	14.4	159.0	13 34	3	.13	3.34	79.8	1.67	16.0	158.8	14 81	4	.15	3.71	79.8	1.85	160
180	16.2	178.6	16.87	4	.19	4.23	89.8	2.11	18.0	178.2	18.72	6	.22	4 70	89.7	2.34	180
200	18.0	198.0	20.80	6	.25	5.22	99.7	2.60	20.0	197.6	23.07	8	.30	5.79	99.6	2.88	200
220	19.8	217.4	25 13	8	.33	6.31	109.6	3.14	22.0	216.8	27.86	.10	.41	7 00	109.5	3.48	220
240	21.6	236.6	29.85	.10	.44	7.50	119.4	3.73	24.0	235.8	33.09	.13	.54	8.31	119.3	4.13	240
260	23.4	255.7	34.97	.13	.57	8.79	129.3	4.37	26.0	254.7	38.75	.16	.70	9.75	129.1	4.83	260
280	25.2	274.6	40.48	.17	.71	10.18	139.1	5.05	28.0	273.4	44.84	.20	.88	11.30	138.9	5.58	280
300	27.0	293.4	46.37	.20	.87	11.67	148.9	5.78	30.0	291.9	51.35	.25	1.07	12.96	148.6	6.39	300
320	28.8	312.0	52.65	.2	1.1	13.27	158.7	6.56	32.0	310.2	58.27	.3	1.3	14.73	158.3	7.25	320
340	30.6	330.4	59.30	.3	1.3	14.97	168.4	7.38	34.0	328.2	65.58	.4	1.6	16.60	168.0	8 16	340
360	32 4	348.7	66.32	.3	1.5	16.76	178.1	8.25	36.0	346.0	73.30	.4	1.9	18.58	177.6	9.11	360
380	34.2	366.7	73.70	.4	1.8	18.65	187.8	9.16	38.0	363.6	81.40	.5	2.2	20.67	187.2	10.11	380
400	36.0	384.5	81.43	.5	2.1	20.63	197.4	10.12	40.0	380.9	89.89	.6	2.6	22.86	196.8	11.15	400
420	37.8	402.1	89 51	.5	2.4	22.71	207.0	11.12	42.0	398.0	98.75	.7	3.0	25.16	206 3	12.24	420
440	39.6	419.5	97.94	.6	2.8	24.89	216.5	12.16	44.0	414.8	107.97	.7	3.5	27.56	215.7	13.38	440
460	41.4	436.6	106.72	.7	3.2	27.17	226.1	13.24	46.0	431.2	117.54	.8	3.9	30.06	225.1	14.56	460
480	43 2	453.4	115.88	.8	3.6	29.54	235.5	14 36	48.0	447.4	127.46	1.0	4.5	32 67	234.5	15.77	480
500	45.0	470.0	125.24	.9	4.1	32.00	245.0	15 52	50.0	463 2	137.71	1.1	5.1	35.37	243.8	17.02	500
520	46.8	486.4	134 97	1.0	4.6	34.55	254.3	.6 71	52.0	478.8	148.29	1.2	5.7	38.17	253.0	18.31	520
540	48.6	502 4	145.01	1.1	5.2	37.19	263.7	17.94	54.0	494.0	159.17	1.3	6.4	41.07	262.2	19.63	540
560	50.4	518.2	155.34	1.2	5.8	39 92	272.9	19.20	56.0	508.8	170.36	1.5	7.2	44.07	271.3	20.99	560
580	52.2	533.7	165.96	1.3	6.4	42.74	282.2	20.50	58.0	523.3	181 88	1.6	8 0	47.16	280.4	22.39	580
600	54.0	548.9	176.86	1.5	7.1	45.64	291.4	21.83	60.0	537.5	193.58	1.7	8.8	50.33	289.4	23.81	600
620	55 8	563.8	188.03	1.6	7.8	48.63	300.5	23.20	62.0	551.2	205 60	1.8	9.8	53.60	298.3	25.26	620
640	57.6	578.4	199.46	1.7	8.6	51 70	309.6	24.59	64.0	564.6	217.87	2.1	10.7	56 96	307.1	26.74	640
660	59.4	592.6	211.15	1.9	9.4	54.85	318.6	26.00	66.0	577 6	230.38	2.3	11.7	60.41	315.9	28.25	660
680	61 2	606.5	223.09	2.1	10.3	58 09	327.6	27.45	68.0	590.3	243.12	2.4	12.8	63.94	324.6	29.77	680
700	63.0	620.1	235.28	2.2	11.2	61.40	336.5	28.93	70.0	602.5	256.07	2.6	14.0	67.56	333.3	31.32	700

TABLE I.

l_1	22° Curve.								24° Curve.							l_1
	$I°$	x_1	y_1	e	e'	F	x'	y'	$I°$	x_1	y_1	e	e'	F	x'	y'	
40	4.4	40	1.02			.26	20	.13	4.8	40	1.12			.28	20	.14	40
60	6.6	59.9	2.30			.58	30	.29	7.2	59.9	2.51			.63	30	.31	60
80	8.8	79.8	4.09		.01	1.02	40	51	9.6	79.8	4.46	.01	.02	1.12	40	56	80
100	11.0	99.6	6.38	.01	2	1.60	49.9	80	12.0	99.6	6.96	1	4	1.74	49.9	.87	100
120	13.2	119.4	9.18	2	7	2.30	59.9	1.15	14.4	119.2	10.01	2	8	2.51	59.9	1.25	120
140	15.4	139.0	12.48	3	.12	3.13	69.8	1.56	16.8	138.8	13.60	4	14	3.41	69.8	1.70	140
160	17.6	158.5	16.27	4	.18	4.08	79.7	2.03	19.2	158.2	17.73	5	.21	4.45	79.7	2.21	160
180	19.8	177.9	20.56	6	.27	5.16	89.6	2.57	21.6	177.5	22.39	8	.31	5.62	89.6	2.79	180
200	22.0	197.1	25.33	9	.37	6.37	99.5	3.16	24.0	196.5	27.57	.11	.42	6.93	99.4	3.44	200
220	24.2	216.1	30.58	.12	.50	7.69	109.3	3.81	26.4	215.4	33.27	.15	.58	8.38	109.2	4.15	220
240	26.4	235.0	36.30	.15	.65	9.13	119.1	4.53	28.8	234.0	39.49	.18	.77	9.97	119.0	4.92	240
260	28.6	253.6	42.49	.19	.83	10.71	128.9	5.30	31.2	252.4	46.20	.23	.99	11.67	128.7	5.75	260
280	30.8	272.0	49.14	.24	1.05	12.42	138.6	6.12	33.6	270.5	53.40	.29	1.25	13.51	138 4	6.64	280
300	33.0	290.2	56.24	.29	1.30	14.22	148.3	7.00	36.0	288.4	61.08	.35	1.54	15.48	148.0	7.59	300
320	35.2	308.1	63.78	.4	1.6	16.15	158.0	7.93	38.4	305.9	69.22	.4	1.9	17.58	157.6	8.59	320
340	37.4	325.8	71.75	.4	1.9	18.21	167.6	8.92	40.8	323.2	77.82	.5	2.3	19.81	167.2	9.65	340
360	39.6	343.2	80.15	.5	2.3	20.38	177.2	9.95	43.2	340.1	86 86	.6	2.7	22.15	176.6	10.77	360
380	41.8	360.3	88.95	.6	2.7	22.66	186.7	11.03	45.6	356.6	96.33	.7	3.2	24.63	186.0	11.93	380
400	44.0	377.0	98.15	.7	3.1	25.05	196.1	12.17	48.0	372.8	106.22	.8	3.7	27.22	195.4	13.14	400
420	46.2	393.5	107.75	.8	3.6	27.56	205.5	13.34	50.4	388.6	116.50	.9	4.3	29.94	204.7	14.40	420
440	48.4	409.6	117.72	.9	4.2	30.18	214.9	14.56	52.8	404.1	127.17	1.0	4.9	32.77	213.9	15.70	440
460	50.6	425.4	128.05	1.0	4.8	32.92	224.1	15.82	55.2	419.1	138.21	1.2	5.6	35.72	223.1	17.05	460
480	52.8	440.8	138.73	1.1	5.5	35.75	233.3	17.12	57.6	433.7	149.60	1.3	6.4	38.77	232.1	18.44	480
500	55.0	455.9	149.75	1.2	6.2	38.69	242.5	18.46	60.0	447.9	161.32	1.5	7.3	41.93	241.1	19.85	500
520	57.2	470.5	161.10	1.4	7.0	41.74	251.6	19.84	62.4	461.6	173.36	1.6	8.2	45.22	250.0	21.31	520
540	59.4	484.8	172.76	1.5	7.8	44.89	260.6	21.25	64.8	474.9	185.70	1.8	9.2	48.60	258.9	22.80	540
560	61.6	498.6	184.71	1.7	8.7	48.14	269.5	22.70	67.2	487.7	198.32	2.0	10.2	52.09	267.6	24.31	560
580	63.8	512.1	196.94	1.8	9.7	51.48	278.4	24.17	69.6	500.1	211.21	2.2	11.4	55.68	276.3	25.84	580
600	66.0	525.1	209.44	2.0	10.7	54.93	287.2	25.67	72.0	511.9	224.34	2.4	12 6	59.37	284.9	27.40	600
620	68.2	537.7	222.19	2.2	11.8	58.46	295.9	27.19	74.4	523.3	237.70	2.6	13.9	63.15	293.4	28.99	620
640	70.4	549.9	235.17	2 4	13.0	62.09	304.5	28.74	76 8	534.2	251.26	2.8	15 3	67.08	301.7	30.60	640
660	72.6	561.6	248.37	2 6	14.2	65.80	313.1	30.30	79.2	544.6	265 00	3.0	16.8	70.98	310.0	32.23	660
680	74.8	572.9	261.77	2 8	15.5	69.61	321.6	31.89	81.6	554.4	278.91	3.2	18.4	75.03	318 2	33.86	680
700	77.0	583.7	275.36	3.0	17.0	73.49	329.9	33.49	84.0	563.8	292.97	3.4	20.1	79.18	326.3	35.51	700

TABLE I.

l_1	26° Curve.								28° Curve.							l_1
	$I°$	x_1	y_1	e	e'	F	x'	y'	$I°$	x_1	y_1	e	e'	F	x'	y'	
40	5.2	40.0	1.21			.30	20	.15	5.6	39.9	1.30			.33	20	.16	40
50	6.5	49.9	1.89			.47	25	.24	7.0	49.9	2.03			.51	25	.25	50
60	7.8	59.9	2.72			.68	30	.34	8.4	59.8	2.93			.74	30	.37	60
70	9.1	69.8	3.70		.01	.93	35	.46	9.8	69.8	3 99		.01	1.00	34.9	.50	70
80	10.4	79.7	4.83	.01	2	1.21	39.9	.60	11.2	79.7	5.20	.01	2	1.30	39.9	.65	80
90	11.7	89.6	6.11	1	3	1.53	44.9	.76	12.6	89.5	6.57	1	3	1 64	44.9	.82	90
100	13.0	99.5	7.54	2	5	1.89	49.9	.94	14.0	99.4	8.11	2	5	2.03	49.9	1.01	100
110	14.3	109.3	9.11	2	6	2.28	54.9	1.14	15.4	109.2	9.80	2	8	2.46	54.8	1.22	110
120	15.6	119.1	10.83	3	9	2.71	59.8	1.35	16.8	119.0	11.65	3	.11	2.93	59.8	1.45	120
130	16.9	128.9	12.70	3	.12	3.18	64.8	1.58	18.2	128.7	13.66	4	.14	3.43	64.7	1.70	130
140	18.2	138.6	14.72	4	.15	3.69	69.7	1.84	19.6	138 4	15.83	5	.18	3.97	69.7	1.97	140
150	19.5	148.3	16.88	5	.19	4.24	74.7	2.11	21.0	148.0	18.15	6	.23	4.56	74.6	2.26	150
160	20.8	157.9	19.18	6	.24	4.82	79.6	2.40	22.4	157.6	20.62	.1	.8	5.18	79.6	2.57	160
170	22.1	167.5	21.63	8	.30	5.44	84.6	2.70	23.8	167.1	23.24	.1	.8	5.84	84.5	2.90	170
180	23.4	177.0	24.21	9	.36	6.09	89.5	3.02	25.2	176.5	26.02	.1	.4	6.54	89.4	3.24	180
190	24.7	186 5	26.94	.11	.43	6.78	94.4	3.36	26.6	185.9	28.95	.1	.5	7.29	94.3	3.61	190
200	26.0	195.9	29.81	.13	.51	7.50	99.3	3.71	28.0	195.3	32.02	.1	.6	8.07	99.2	3.99	200
210	27.3	205.3	32 81	.2	.6	8.26	104.2	4.09	29.4	204.6	35.25	.2	.7	8.89	104.1	4.39	210
220	28.6	214.6	35.95	.2	.7	9.06	109.1	4.48	30.8	213.7	38.61	.2	.8	9.75	108.9	4.81	220
230	29.9	223.8	39.23	.2	.8	9.90	113.9	4.89	32.2	222.8	42.12	.2	.9	10.64	113.8	5.24	230
240	31.2	233.0	42.64	.2	.9	10.77	118.8	5.31	33.6	231.9	45.77	.3	1.0	11.58	118.6	5.69	240
250	32.5	242.1	46.19	.2	1.0	11.67	123.7	5.75	35.0	240.8	49.56	.3	1.2	12.55	123.4	6.16	250
260	33.8	251.1	49.87	.3	1.1	12.61	128.5	6.20	36.4	249.7	53.49	.3	1.4	13.56	128.2	6.64	260
270	35.1	260.0	53.67	.3	1.3	13.59	133.3	6.67	37.8	258.5	57.55	.4	1.5	14.61	133.0	7.14	270
280	36.4	268.9	57.60	.3	1.5	14.60	138.1	7.16	39.2	267.2	61.75	.4	1.7	15.69	137.8	7.66	280
290	37.7	277.7	61.66	.4	1.6	15.65	142.9	7.66	40.6	275.8	66.07	.4	1.9	16.81	142.6	8.20	290
300	39.0	283.4	65.85	.4	1.8	16.73	147.7	8.17	42.0	284.3	70.53	.5	2.1	17.97	147.3	8.75	300
310	40.3	295.0	70.16	.5	2.0	17.85	152.4	8.70	43.4	292.7	75.12	.5	2.3	19.16	152.1	9.31	310
320	41.6	303.5	74.58	.5	2.2	19.00	157.2	9.25	44.8	301.0	79.83	.5	2.6	20.39	156.8	9.89	320
330	42.9	312.0	79.12	.6	2.4	20.18	161.9	9.81	46.2	309.2	84.66	.6	2.8	21.66	161.5	10.48	330
340	44.2	320.3	83.78	.6	2.6	21.39	166.7	10.38	47.6	317.3	89.61	.6	3.1	22.96	166.1	11.09	340
350	45.5	328.5	88.55	.7	2.9	22 64	171.4	10.97	49.0	325.2	94.68	.7	3.4	24.29	170.8	11.71	350
360	46.8	336.7	93.44	.7	3.1	23.92	176.1	11.57	50.4	333.1	99 86	.8	3.7	25.66	175.4	12.34	360
370	48.1	344.8	98.44	.7	3.4	25.23	180.8	12.18	51.8	340.9	105.16	.9	4.0	27.07	180.0	12.99	370

TABLE I.

l_1	32° Curve.								36° Curve.								l_1
	$I°$	x_1	y_1	e	e'	F	x'	y'	$I°$	x_1	y_1	e	e'	F	x'	y'	
30	4.8	30	.84			.21	15	.10	5.4	30	.94			.24	15	.12	30
40	6.4	39.9	1.49			.37	20	.18	7.2	39.9	1.67			.42	20	.21	40
50	8.0	49.9	2.32		.01	.58	25	.29	9.0	49.9	2.61		.01	.65	25	.32	50
60	9.6	59.8	3.35	.01	2	.84	30	.42	10.8	59.8	3.76	.01	2	.94	30	.47	60
70	11.2	69.7	4.55	1	3	1.14	34.9	.57	12.6	69.7	5.11	1	4	1.28	34.9	.64	70
80	12.8	79 6	5.93	1	5	1.49	39.9	.74	14.4	79.5	6.67	1	6	1.67	39.9	.83	80
90	14.4	89.4	7.50	2	7	1.88	44.9	.94	16.2	89.3	8.43	2	9	2.11	44.9	1.05	90
100	16.0	99.2	9.25	2	.10	2.32	49.9	1.16	18.0	99.0	10.40	3	.13	2.61	49.8	1.30	100
110	17.6	109.0	11.18	3	.13	2.80	54.8	1.39	19.8	108.7	12.56	4	.16	3.15	54.8	1.57	110
120	19.2	118.7	13.29	4	.17	3.34	59.8	1.66	21.6	118.3	14.92	5	.22	3.75	59.7	1.86	120
130	20.8	128.3	15.58	5	.21	3.91	64.7	1.94	23.4	127.8	17.48	6	.28	4.39	64.6	2.18	130
140	22.4	137.9	18.04	7	.25	4.53	69.6	2.25	25.2	137.3	20.24	8	.35	5.09	69.5	2.52	140
150	24.0	147.4	20.68	8	.31	5.20	74.5	2.58	27.0	146.7	23.19	.10	.44	5.84	74.4	2.89	150
160	25.6	156.8	23.49	.1	.4	5.91	79.4	2.93	28.8	156.0	26.33	.1	.5	6.63	79.3	3.28	160
170	27 2	166.2	26.47	.1	.5	6.67	84.3	3.30	30.6	165.2	29.65	.1	.6	7.48	84.2	3.69	170
180	28.8	175.5	29.62	.1	.6	7.46	89.2	3.69	32.4	174.3	33.16	.2	.7	8.38	89.0	4.12	180
190	30.4	184.7	32.93	.2	.7	8.31	94.1	4.10	34.2	183.3	36.85	.2	.9	9.32	93.9	4.58	190
200	32.0	193.8	36.41	.2	.8	9.20	98.9	4.53	36.0	192.2	40.72	.2	1.0	10.31	98.7	5.06	200
210	33.6	202.9	40.05	.2	.9	10.13	103.8	4.98	37.8	201.0	44.75	.3	1.2	11.35	103.5	5.56	210
220	35.2	211.8	43.85	.3	1.1	11.10	108.6	5.45	39.6	209.7	48.97	.3	1.4	12.44	108.2	6.08	220
230	36.8	220.7	47.81	.3	1.2	12.12	113.4	5.94	41.4	218.3	53.36	.3	1.6	13.58	113.0	6.62	230
240	38.4	229.4	51.92	.3	1.4	13.19	118.2	6.45	43.2	226.7	57.92	.4	1.8	14.77	117.7	7.18	240
250	40.0	238.1	56.19	.4	1.6	14.29	123.0	6.97	45.0	235.0	62.62	.4	2.0	16.00	122.5	7.76	250
260	41.6	246.6	60.60	.4	1.8	15.43	127.7	7.52	46.8	243.2	67.48	.5	2.3	17.27	127.1	8.36	260
270	43.2	255.0	65.15	.4	2.0	16.62	132.5	8.08	48.6	251.2	72 50	.5	2.6	18.59	131.8	8.97	270
280	44.8	263.3	69.85	.5	2.3	17.84	137.2	8.66	50.4	259.1	77.67	.6	2.9	19.96	136.4	9.60	280
290	46.4	271.5	74.69	.5	2.5	19.11	141.9	9.25	52.2	266.8	82.98	.6	3.2	21.37	141.1	10.25	290
300	48.0	279.6	79.67	.6	2.8	20.42	146.5	9.86	54.0	274.4	88.43	.7	3.5	22.82	145.7	10.92	300
310	49.6	287.5	84.78	.6	3.1	21.76	151.2	10.48	55.8	281.9	94.02	.8	3.9	24.31	150.2	11.60	310
320	51.2	295.4	90.01	.7	3.4	23.15	155.8	11.12	57.6	289.2	99.73	.8	4.3	25.85	154.8	12.30	320
330	52.8	303.1	95.38	.8	3.7	24.57	160.4	11.77	59.4	296.3	105.57	.9	4.7	27.42	159.3	13.00	330
340	54.4	310.6	100.87	.8	4.1	26.04	165.0	12.44	61.2	303.2	111.54	1.0	5.1	29.04	163.8	13.72	340
350	56.0	318.0	106.48	.9	4.5	27.54	169.5	13.12	63.0	310.0	117.64	1.1	5 6	30.70	168.2	14.46	350
360	57.6	325.3	112.20	1.0	4.9	29.08	174.1	13.82	64.8	316.7	123.85	1.2	6.1	32.40	172.6	15.21	360

TABLE I.

l_1	40° Curve.								44° Curve.							l_1
	I°	x_1	y_1	e	e'	F	x'	y'	I°	x_1	y_1	e	e'	F	x'	y'	
30	6.0	30	1.05			.26	15	.13	6.6	29.9	1.15			.29	15	.14	30
40	8 0	39 9	1.86			.46	20	.23	8.8	39.9	2.04			.51	20	.25	40
50	10.0	49.8	2.90		.01	.73	25	.36	11.0	49.8	3.19		.01	.80	25	.40	50
60	12.0	59.7	4.17	.01	3	1.04	29.9	.52	13.2	59.7	4.59	.01	3	1.15	29.9	.57	60
70	14.0	69.6	5.68	1	5	1.42	34.9	.71	15.4	69.5	6.24	1	6	1.56	34.9	.78	70
80	16.0	79.4	7.40	2	7	1.86	39.9	.93	17.6	79.2	8.14	2	9	2.04	39.9	1.02	80
90	18.0	89 1	9.36	3	.11	2.35	44.8	1.17	19.8	88.9	10.28	3	.13	2 58	44.8	1.28	90
100	20.0	98.8	11.53	4	.15	2.89	49.8	1.44	22.0	98.5	12.66	4	.18	3.18	49.7	1.58	100
110	22.0	108 4	13.93	5	.20	3.50	54.7	1.74	24.2	108.0	15.29	6	.25	3.84	54.7	1.90	110
120	24.0	117.9	16.54	6	.27	4.16	59.7	2.06	26.4	117.5	18.15	8	.32	4.56	59.5	2.26	120
130	26.0	127.3	19.37	8	.35	4.87	64.5	2.41	28.6	126.8	21.25	.10	.41	5.35	64.5	2.65	130
140	28.0	136.7	22.42	.10	.44	5.65	69.4	2.79	30.8	136.0	24.57	.12	.52	6.21	69.3	3.06	140
150	30.0	145.9	25.67	.13	.53	6.48	74.3	3.19	33.0	145.1	28.12	.14	.65	7.11	74.2	3.50	150
160	32.0	155.1	29.13	.2	.6	7.36	79.2	3.62	35.2	154.1	31.89	.2	.8	8.08	79.0	3.97	160
170	34.0	164.1	32.79	.2	.8	8.30	84.0	4.08	37.4	162.9	35.88	.2	.9	9.10	83.8	4.46	170
180	36.0	173 0	36.65	.2	1.0	9.29	88.8	4.55	39.6	171.6	40.07	.2	1.1	10.19	88.6	4.97	180
190	38.0	181.8	40.70	.2	1.1	10.33	93.6	5.05	41.8	180.1	44.47	.3	1.3	11.33	93.3	5.51	190
200	40.0	190.4	44.95	.3	1.3	11.43	98.4	5.58	44.0	188.5	49.07	.3	1.6	12.52	98.0	6.08	200
210	42.0	199.0	49.38	.3	1.5	12.58	103.1	6.12	46.2	196 7	53.87	.4	1.8	13.78	102.7	6.67	210
220	44 0	207.4	53.99	.4	1.7	13.78	107.8	6.69	48.4	204.8	58.86	.4	2.1	15.09	107.4	7.28	220
230	46 0	215.6	58.77	.4	2.0	15 08	112 5	7.28	50.6	212.7	64.02	.5	2.4	16.46	112.0	7.91	230
240	48.0	223.7	63.73	.5	2.2	16.33	117.2	7.88	52.8	220.4	69.36	.5	2.8	17.87	116.6	8.56	240
250	50.0	231.6	68.85	.5	2.5	17.68	121.9	8.51	55.0	227.9	74.87	.6	3.1	19.34	121.2	9.23	250
260	52.0	239.4	74.14	.6	2.8	19.08	126.5	9.15	57.2	235.2	80.55	.7	3.5	20.87	125.8	9.92	260
270	54.0	247.0	79.58	.6	3.2	20.53	131.1	9 81	59.4	242.4	86.38	.7	3.9	22.45	130.3	10.62	270
280	56.0	254.4	85.18	.7	3.6	22.03	135.6	10.49	61.6	249.3	92.35	.8	4.3	24.07	134.8	11.35	280
290	58.0	261.6	90.92	.8	4.0	23 58	140.2	11.19	63.8	256.0	98.47	.9	4.8	25.74	139.2	12.08	290
300	60.0	268.7	96.79	.9	4.4	25.17	144.7	11.90	66.0	262.5	104.72	1.0	5.3	27.46	143.6	12.83	300
310	62.0	275.6	102.80	.9	4.9	26.80	149.1	12.63	68.2	268.8	111.09	1.1	5.9	29.23	147.9	13.59	310
320	64.0	282.3	108.94	1.0	5.3	28.48	153.6	13 37	70.4	274.9	117.58	1.2	6.5	31.05	152.2	14.37	320
330	66 0	288.8	115.19	1.1	5.8	30.20	158.0	14.12	72.6	280.8	124.18	1.3	7.1	32.90	156.5	15 15	330
340	68.0	295.1	121.56	1.2	6.4	31.97	162.3	14.88	74.8	286.4	130.88	1.4	7 8	34.80	160.8	15.94	340
350	70.0	301.2	128.03	1.3	7.0	33.78	166.6	15.66	77.0	291.8	137.68	1 5	8.5	36.74	165.0	16.74	350
360	72.0	307.2	134.61	1.4	7.6	35.64	170.9	16.45	79.2	297.0	144.57	1.6	9.3	38.74	169.1	17.55	360

TABLE I.

l_1	48° Curve.								52° Curve.								l_1
	$I°$	x_1	y_1	e	e'	F	x'	y'	$I°$	x_1	y_1	e	e'	F	x'	y'	
30	7.2	29.9	1.25			.32	15	.16	7.8	29.9	1.36			.34	15	0.17	30
40	9.6	39.9	2.23		.01	.56	20	.28	10.4	39.9	2.42		.01	.60	20	.30	40
50	12.0	49.8	3.48	.01	2	.87	25	.43	13.0	49.7	3.77	.01	2	.94	25	.47	50
60	14.4	59.6	5.00	1	4	1.25	29.9	.62	15.6	59.5	5.42	1	4	1.36	29.9	.68	60
70	16.8	69.4	6 80	2	7	1.70	34.9	.85	18.2	69.3	7.36	2	8	1.85	34.9	.92	70
80	19.2	79.1	8.87	3	.11	2.22	39.8	1.11	20.8	78.9	9.59	3	.12	2.41	39.8	1.20	80
90	21.6	88.7	11.19	4	.15	2.81	44.8	1.40	23.4	88.5	12.11	5	.18	3.04	44.7	1.51	90
100	24.0	98.2	13.79	5	.22	3.47	49.7	1.72	26.0	97.9	14.90	6	.26	3.75	49.6	1.86	100
110	26.4	107.7	16.64	7	.29	4.19	54.6	2.07	28.6	107.3	17.98	.1	.2	4.53	54.5	2.24	110
120	28.8	117.0	19.74	9	.38	4.98	59.5	2.46	31.2	116.5	21.32	.1	.4	5.38	59.4	2.65	120
130	31.2	126.2	23 10	.11	.49	5.83	64.3	2.87	33.8	125.5	24.93	.1	.6	6.31	64.2	3.10	130
140	33.6	135.2	26.70	.14	.62	6.75	69.2	3.32	36.4	134.4	28.80	.2	.7	7.30	69.1	3.58	140
150	36.0	144.2	30.54	.17	.77	7.74	74.0	3.79	39.0	143.2	32.92	.2	.9	8.37	73.8	4.09	150
160	38.4	153 0	34.61	.2	.9	8.79	78.8	4.30	41.6	151.8	37.29	.3	1.1	9.50	78 6	4.62	160
170	40.8	161.6	38.91	.2	1.1	9 90	83.6	4.83	44.2	160.1	41.89	.3	1.3	10.70	83.3	5.19	170
180	43 2	170.0	43.43	.3	1.3	11.07	88.3	5.39	46.8	168.3	46.72	.4	1.6	11.96	88.0	5.79	180
	56° Curve.								60° Curve.								
30	8.4	29.9	1.46			.37	15	.18	9.0	29.9	1.57		.01	.39	15	.20	30
40	11.2	39.8	2.60		.01	.65	20	.32	12.0	39.8	2.78	.01	2	.70	20	.35	40
50	14.0	49.7	4.06	.01	2	1.02	24.9	.51	15.0	49.7	4.34	1	4	1.09	24.9	.54	50
60	16.8	59.5	5.83	2	5	1.46	29.9	.73	18.0	59.4	6.24	2	7	1.57	29 9	.78	60
70	19.6	69.2	7.92	3	9	1.99	34 9	.99	21.0	69.1	8.47	3	.12	2.13	34.8	1.06	70
80	22.4	78.8	10.31	4	.15	2.59	39.8	1.29	24.0	78.6	11 03	4	.18	2.77	39.8	1.37	80
90	25.2	88 3	13.01	5	21	3.27	44.7	1.62	27.0	88.0	13.91	6	.25	3.50	44.7	1.73	90
100	28.0	97.6	16.01	6	.30	4.03	49.6	1.99	30.0	97.3	17.12	8	.35	4.32	49.5	2.13	100
110	30.8	106.9	19.31	.1	.4	4.87	54.5	2.40	33.0	106.4	20.62	.1	.5	5.21	54.4	2.57	110
120	33.6	116.0	22.89	.1	.5	5.79	59.3	2.85	36.0	115.3	24.43	.1	.6	6.19	59.2	3.04	120
130	36.4	124.9	26.75	.2	.7	6.78	64.1	3.32	39.0	124.1	28 53	.2	.8	7.25	64.0	3.54	130
140	39.2	133.6	30.88	.2	.9	7.85	68.9	3.83	42.0	132.7	32.92	.2	1.0	8.38	68.8	4.08	140
150	42.0	142.2	35.27	.2	1.2	8.98	73.7	4.37	45.0	141.0	37.58	.2	1.2	9.60	73.5	4.65	150
160	44.8	150.5	39.92	.3	1.3	10.20	78.4	4.95	48.0	149.1	42.49	.3	1.5	10.89	78.2	5.26	160
170	47.6	158.6	44.81	.3	1.5	11.48	83.1	5.55	51.0	157.0	47.65	.4	1.8	12.26	72.8	5.89	170
180	50.4	166.6	49.93	.4	1.8	12.83	87.7	6.17	54.0	164.7	53.06	.4	2.1	13.69	87.4	6.55	180

TABLE II. COÖRDINATES $y = lC$; $x = l - lE$.

$\phi°$	C	E	$\phi°$	C	E
1	0.00582 581	0.00003	31	0.17661 545	0.02888
2	1163 582	12	32	.18206 542	3075
3	1745 581	27	33	.18748 540	3267
4	2326 581	49	34	.19288 538	3464
5	2907 581	76	35	.19826 535	3667
6	3488 580	110	36	.20361 533	3876
7	4068 580	149	37	.20894 530	4090
8	4648 579	195	38	.21424 526	4310
9	5227 578	246	39	.21950 524	4535
10	5805 578	304	40	.22474 521	4765
11	0.06383 576	0.00368	41	0.22995 518	0.05001
12	6959 576	438	42	.23513 515	5241
13	7535 575	514	43	.24028 512	5487
14	8110 574	595	44	.24540 509	5739
15	8684 573	683	45	.25049 505	5995
16	9257 571	777	46	.25554 503	6256
17	9828 570	877	47	.26057 499	6523
18	.10398 569	983	48	.26556 496	6794
19	.10967 568	1094	49	.27052 492	7070
20	.11535 566	1212	50	.27544 488	7352
21	0.12101 564	0.01335	51	0.28032 486	0.07638
22	.12665 563	1464	52	.28518 482	7929
23	.13228 561	1599	53	.29000 478	8224
24	.13789 559	1740	54	.29478 474	8525
25	.14348 557	1887	55	.29952 471	8830
26	.14905 556	2040	56	.30423 467	9140
27	.15461 553	2198	57	.30890 462	9454
28	.16014 551	2362	58	.31352 459	9773
29	.16565 549	2531	59	.31811 455	.10096
30	.17114 547	2707	60	.32266	.10423

TABLE III. DEFLECTION ANGLES $d = \frac{1}{3}A - B$.

n	ϕ for $I+3=1$.	A	Inst. at sta. $n'' = 0$. B For $I+3=$ 4°	6°	8°	10°	12°	14°	16°	18°	20°
0	.00	.00									
.05	.0075	.0025									
.1	.03	.01									
.15	.0675	.0225									
.2	.12	.04									
.25	.1875	.0625									
.3	.27	.09									
.35	.3675	.1225									
.4	.48	.16									1
.45	.6075	.2025						1	1	1	1
.5	.75	.25					1	1	1	2	3
.55	.9075	.3025				1	1	2	3	4	5
.6	1.08	.36			1	1	2	3	4	6	9
.65	1.2675	.4225			1	2	3	5	7	10	14
.7	1.47	.49		1	1	3	5	7	11	16	22
.75	1.6875	.5625		1	2	4	7	11	17	24	33
.8	1.92	.64		1	3	6	11	17	25	36	49
.85	2.1675	.7225	1	2	4	9	15	24	36	52	71
.9	2.43	.81	1	3	6	12	21	34	51	73	100
.95	2.7075	.9025	1	4	9	17	30	47	71	102	139
1.	3.	1.	1	5	12	23	41	64	97	138	191

TABLE III. DEFLECTION ANGLES $d = \frac{1}{8}A - B$.

n	ϕ for $I+3=1$.	Inst. at sta. $n''=1$. A	B For $I+3=$ 4°	6°	8°	10°	12°	14°	16°	18°	20°	Inst. at sta. $n''=.5$. A	B For $I+3=$ 8°	12°	16°	20°	Inst. at sta. $n''=.25$. A	B For $I+3=$ 4°	8°	12°	14°	16°	18°	20°	Inst. at sta. $n''=.75$. A	B For $I+3=$ 6°	10°	14°	16°	18°	20°	n
.0	.00	1.	1	5	12	23	41	64	97	138	191	.25		1	1	3	.0625								.5625	1	4	11	17	24	33	0
.05	.0075	1.0525	1	4	11	20	36	58	86	124	171	.2775			1	2	.0775								.6025	1	4	10	15	21	29	.05
.1	.03	1.11	1	4	9	18	32	51	76	109	150	.31			1	2	.0975								.6475	1	3	8	12	17	24	.1
.15	.0675	1.1725	1	3	8	16	28	44	66	95	130	.3475			1	1	.1225								.6975	1	2	7	10	14	20	.15
.2	.12	1.24	1	3	7	13	23	37	56	80	110	.39				1	.1525								.7525		2	6	8	12	16	.2
.25	.1875	1.3125	1	2	6	11	20	31	47	68	93	.4375					.1875								.8125		1	4	6	9	12	.25
.3	.27	1.39	1	2	5	9	16	26	39	56	77	.49					.2275								.8775		1	3	4	6	9	.3
.35	.3675	1.4725		2	4	7	13	21	31	44	61	.5475					.2725								.9475		1	2	3	4	6	.35
.4	.48	1.56		1	3	6	10	16	24	34	47	.61					.3225								1.0225			1	2	3	4	.4
.45	.6075	1.6525		1	2	4	8	12	18	26	36	.6775					.3775								1.1025			1	1	2	2	.45
.5	.75	1.75		1	2	3	6	9	14	19	26	.75					.4375								1.1875				1	1	1	.5
.55	.9075	1.8525			1	2	4	6	9	13	19	.8275					.5025						1	1	1.2775							.55
.6	1.08	1.96			1	1	3	4	6	9	13	.91					.5725					1	1	1	1.3725							.6
.65	1.2675	2.0725				1	2	3	4	6	8	9975					.6475			1	1	2	3	4	1.4725							.65
.7	1.47	2.19					1	1	2	3	5	1.09					.7275		1	2	3	4	6	8	1.5775							.7
.75	1.6875	2.3125						1	1	2	3	1.1875			1	1	.8125		1	3	4	6	9	12	1.6875							.75
.8	1.92	2.44								1	1	1.29		1	1	2	.9025		1	4	6	9	13	18	1.8025							.8
.85	2.1675	2.5725									1	1.3975		1	3	6	.9975		2	6	10	15	21	29	1.9225							.85
.9	2.43	2.71										1.51	1	2	5	9	1.0975		3	9	15	22	32	44	2.0475						1	.9
.95	2.7075	2.8525										1.6275	1	3	8	16	1.2025	1	4	14	22	33	46	65	2.1775					1	1	.95
1.	3.	3.										1.75	2	6	14	26	1.3125	1	6	20	31	47	68	93	2.3125			1	1	2	3	1.

TABLE IV.—RADII, AND DEFLECTION ANGLES IN MINUTES PER FOOT OF LENGTH.

Deg. *D*	Radius *R*	Def. per Foot.	Deg. *D*	Radius *R*	Def. per Foot.	Deg. *D*	Radius *R*	Def. per Foot.	Deg. *D*	Radius *R*	Def. per Foot.	Deg. *D*	Radius *R*	Def. per Foot.
0° 0′			0° 30′	11460.0	.15	1° 0′	5730.00	.3	1° 30′	3820.00	.45	2° 0′	2865.00	.6
1	343800.0	.005	31	11090.3	.155	1	5636.05	.305	31	3778.01	.455	1	2841.32	.605
2	171900.0	.01	32	10743.8	.16	2	5545.16	.31	32	3736.95	.46	2	2818.02	.61
3	114600.0	.015	33	10418.2	.165	3	5457.15	.315	33	3696.78	.465	3	2795.12	.615
4	85950.0	.02	34	10111.8	.17	4	5371.86	.32	34	3657.44	.47	4	2772.58	.62
5	68760.0	.025	35	9822.86	.175	5	5289.23	.325	35	3618.96	.475	5	2750.40	.625
6	57300.0	.03	36	9550.00	.18	6	5209.09	.33	36	3581.25	.48	6	2728.57	.63
7	49114.3	.035	37	9291.89	.185	7	5131.35	.335	37	3544.34	.485	7	2707.09	.635
8	42975.0	.04	38	9047.38	.19	8	5055.88	.34	38	3508.17	.49	8	2685 98	.64
9	38200.0	.045	39	8815.40	.195	9	4982.61	.345	39	3472.73	.495	9	2665.12	.645
10	34380.0	.05	40	8595.00	.2	10	4911.43	.35	40	3438.00	.5	10	2644.62	.65
11	31254 5	.055	41	8385.37	.205	11	4842.26	.355	41	3403 96	.505	11	2624.43	.655
12	28650.0	.06	42	8185.71	.21	12	4775.00	.36	42	3370.59	.51	12	2604.55	.66
13	26446.2	.065	43	7995.35	.215	13	4709.58	.365	43	3337.86	.515	13	2584.97	.665
14	24557.1	.07	44	7813 65	.22	14	4645.94	.37	44	3305.77	.52	14	2565.68	.67
15	22920.0	.075	45	7640.00	.225	15	4584.00	.375	45	3274.29	.525	15	2546.67	.675
16	21487.5	.08	46	7473.91	.23	16	4523.69	.38	46	3243.40	.53	16	2527.94	.68
17	20223.5	.085	47	7314.89	.235	17	4464.95	.385	47	3213.09	.535	17	2509.50	.685
18	19100.0	.09	48	7162.50	.24	18	4407.70	.39	48	3183 33	.54	18	2491.31	.69
19	18094.7	.095	49	7016.33	.245	19	4351.90	.395	49	3154.13	.545	19	2473.39	.695
20	17190.0	.10	50	6876.00	.25	20	4297.50	.4	50	3125.45	.55	20	2455.72	.7
21	16371.4	.105	51	6741.18	.255	21	4244.45	.405	51	3097.30	.555	21	2438.30	.705
22	15627.2	.11	52	6611.54	.26	22	4192.68	.41	52	3069.64	.56	22	2421.13	.71
23	14947.8	.115	53	6486.79	.265	23	4142.18	.415	53	3042.48	.565	23	2404.20	.715
24	14325.0	.12	54	6366.67	.27	24	4092.86	.42	54	3015.79	.57	24	2387.50	.72
25	13752.0	.125	55	6250.90	.275	25	4044.70	.425	55	2989.56	.575	25	2371 04	.725
26	13223.1	.13	56	6139.29	.28	26	3997.68	.43	56	2963.79	.58	26	2354.79	.73
27	12733.3	.135	57	6031.58	.285	27	3951.73	.435	57	2938.46	.585	27	2338.78	.735
28	12278.6	.14	58	5927.59	.29	28	3906.82	.44	58	2913.56	.59	28	2322.97	.74
29	11855.1	.145	59	5827.12	.295	29	3862.92	.445	59	2889.08	.595	29	2307.38	.745
30	11460.0	.15	60	5730.00	.3	30	3820.00	.45	60	2865.00	.6	30	2292.00	.75

TABLE IV.—RADII, AND DEFLECTION ANGLES IN MINUTES PER FOOT OF LENGTH.

Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.
2° 30′	2292.00	.75	3° 0′	1910 00	.9	3° 30′	1637.15	1.05	4° 0′	1432 50	1.2	4° 30′	1273.33	1.35
31	2276.82	.755	1	1899 45	.905	31	1629.38	1.055	1	1426.55	1.205	31	1268.63	1.355
32	2261.85	.76	2	1889.01	.91	32	1621.70	1.06	2	1420.66	1.21	32	1263.97	1.36
33	2247.06	.765	3	1878.69	.915	33	1614.09	1.065	3	1414.82	1.215	33	1259.34	1.365
34	2232.47	.77	4	1868.48	.92	34	1606.54	1.07	4	1409.01	1.22	34	1254 74	1.37
35	2218.06	.775	5	1858.38	.925	35	1599.07	1.075	5	1403.26	1.225	35	1250.18	1.375
36	2203.85	.78	6	1848.39	.93	36	1591.67	1.08	6	1397.56	1.23	36	1245.66	1.38
37	2189.82	.785	7	1838.50	.935	37	1584.34	1.085	7	1391.90	1.235	37	1241.16	1.385
38	2175.95	.79	8	1828.72	.94	38	1577.07	1.09	8	1386.29	1.24	38	1236.70	1.39
39	2162.27	.795	9	1819.05	.945	39	1569.87	1.095	9	1380.72	1.245	39	1232.26	1.395
40	2148.75	.8	10	1809.48	.95	40	1562.73	1.1	10	1375.20	1.25	40	1227.86	1.4
41	2135.41	.805	11	1800.00	.955	41	1555.66	1.105	11	1369.72	1.255	41	1223.49	1.405
42	2122.22	.81	12	1790.62	.96	42	1548.65	1.11	12	1364.29	1.26	42	1219.15	1.41
43	2109.20	.815	13	1781.35	.965	43	1541.71	1.115	13	1358.90	1.265	43	1215.05	1.415
44	2096.34	.82	14	1772.17	.97	44	1534.82	1.12	14	1353.55	1.27	44	1210.56	1.42
45	2083.63	.825	15	1763.08	.975	45	1528.00	1.125	15	1348.23	1.275	45	1206.31	1.425
46	2071.09	.83	16	1754.08	.98	46	1521.24	1.13	16	1342.93	1.28	46	1202.10	1.43
47	2058.69	.835	17	1745.15	.985	47	1514.54	1.135	17	1337.74	1.285	47	1197.91	1.435
48	2046.43	.84	18	1736.36	.99	48	1507.90	1.14	18	1332.56	1.29	48	1193.75	1.44
49	2034.32	.845	19	1727.63	.995	49	1501.32	1.145	19	1327.42	1.295	49	1189.62	1.445
50	2022.35	.85	20	1719.00	1.	50	1494.78	1.15	20	1322.31	1.3	50	1185.52	1.45
51	2010.53	.855	21	1710.45	1.005	51	1488.32	1.155	21	1317.24	1.305	51	1181.45	1.455
52	1998.84	.86	22	1701.98	1.01	52	1481.90	1.16	22	1312.21	1.31	52	1177.40	1.46
53	1987.29	.865	23	1693.60	1.015	53	1475.54	1.165	23	1307.23	1.315	53	1173 38	1.465
54	1975.86	.87	24	1685.30	1.02	54	1469.23	1.17	24	1302.27	1.32	54	1169.39	1.47
55	1964.57	.875	25	1677.08	1.025	55	1462.98	1.175	25	1297.35	1.325	55	1165.43	1.475
56	1953.41	.88	26	1668.93	1.03	56	1456.78	1.18	26	1292.48	1.33	56	1161.48	1.48
57	1942.37	.885	27	1660.87	1.035	57	1450 63	1.185	27	1287.64	1.335	57	1157 57	1.485
58	1931.46	.89	28	1652.88	1.04	58	1444.54	1.19	28	1282.84	1.34	58	1153.69	1.49
59	1920.67	.895	29	1644.98	1.045	59	1438.50	1.195	29	1278.07	1.345	59	1149.83	1.495
60	1910.00	.9	30	1637.15	1.05	60	1432.50	1.2	30	1273.33	1.35	60	1146.00	1.5

Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.
5° 0′	1146.00	1.5	5° 30′	1041.82	1.65	6° 0′	955.00	1.8	6° 30′	881.54	1.95	7° 0′	818.37	2.1
1	1142.19	1.505	31	1038.68	1.655	1	952.35	1.805	31	879.28	1.955	1	816.62	2.105
2	1138.41	1.51	32	1035.54	1.66	2	949.73	1.81	32	877.04	1.96	2	814.69	2.11
3	1134.66	1.515	33	1032.43	1.665	3	947.11	1.815	33	874.80	1.965	3	812.78	2.115
4	1130.92	1.52	34	1029.34	1.67	4	944.51	1.82	34	872.58	1.97	4	810.85	2.12
5	1127.21	1.525	35	1026.27	1.675	5	941.92	1.825	35	870.38	1.975	5	808.94	2.125
6	1123.53	1.53	36	1023.21	1.68	6	939.35	1.83	36	868.18	1.98	6	807.04	2.13
7	1119.87	1.535	37	1020.18	1.685	7	936.79	1.835	37	865.99	1.985	7	805.15	2.135
8	1116.23	1.54	38	1017.16	1.69	8	934.24	1.84	38	863.82	1.99	8	803.27	2.14
9	1112.62	1.545	39	1014.16	1.695	9	931.71	1.845	39	861.66	1.995	9	801.40	2.145
10	1109.03	1.55	40	1011.17	1.7	10	929.19	1.85	40	859.50	2.	10	799.54	2.15
11	1105.46	1.555	41	1008.21	1.705	11	926.69	1.855	41	857.36	2.005	11	797.68	2.155
12	1101.92	1.56	42	1005.26	1.71	12	924.20	1.86	42	855.22	2.01	12	795.84	2.16
13	1098.40	1.565	43	1002.33	1.715	13	921.72	1.865	43	853.10	2.015	13	794.00	2.165
14	1094.91	1.57	44	999.42	1.72	14	919.25	1.87	44	850.99	2.02	14	792.17	2.17
15	1091.43	1.575	45	996.53	1.725	15	916.80	1.875	45	848.89	2.025	15	790.35	2.175
16	1087.97	1.58	46	993.65	1.73	16	914.36	1.88	46	846.80	2.03	16	788.53	2.18
17	1084.54	1.585	47	990.79	1.735	17	911.94	1.885	47	844.72	2.035	17	786.74	2.185
18	1081.13	1 59	48	987.93	1.74	18	909.52	1.89	48	842 65	2.04	18	784.93	2.19
19	1077.74	1.595	49	985.10	1.745	19	907.13	1.895	49	840.59	2.045	19	783.14	2.195
20	1074.38	1.60	50	982.29	1.75	20	904.74	1.9	50	838.54	2.05	20	781.36	2.2
21	1071.03	1.605	51	979.49	1.755	21	902.36	1.905	51	836.50	2.055	21	779.59	2.205
22	1067.70	1.61	52	976.70	1.76	22	900.00	1.91	52	834.47	2.06	22	777.83	2.21
23	1064.40	1.615	53	973.94	1.765	23	897.65	1.915	53	832.44	2.065	23	776.07	2.215
24	1061.11	1.62	54	971.19	1.77	24	895.31	1.92	54	830.43	2.07	24	774.33	2.22
25	1057.84	1.625	55	968.45	1.775	25	892.99	1.925	55	828.43	2.075	25	772.58	2.225
26	1054.60	1.63	56	965.73	1.78	26	890.67	1.93	56	826.44	2.08	26	770.85	2.23
27	1051.38	1.635	57	963.03	1.785	27	888.37	1.935	57	824.46	2.085	27	769.13	2.235
28	1048.17	1.64	58	960.34	1.79	28	886.08	1.94	58	822.49	2.09	28	767.41	2.24
29	1044.99	1.645	59	957.65	1.795	29	883.80	1.945	59	820.53	2.095	29	765.70	2.245
30	1041.82	1.65	60	955.00	1.8	30	881.54	1.95	60	818.57	2.1	30	764.00	2.25

TABLE IV.—RADII, AND DEFLECTION ANGLES IN MINUTES PER FOOT OF LENGTH.

Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.
7° 30′	764.00	2.25	8° 0′	716.25	2.4	9° 0′	636.67	2.7	10° 0′	573.00	3.	11° 0	520.91	3.3
31	762.31	2.255	2	713.28	2.41	2	634.32	2.71	2	571.10	3.01	2	519.34	3.31
32	760 62	2.26	4	710.33	2.42	4	631.99	2.72	4	569.20	3.02	4	517.77	3.32
33	758.94	2.265	6	707.41	2.43	6	629.66	2.73	6	567.33	3.03	6	516.22	3.33
34	757.27	2.27	8	704.51	2.44	8	627.37	2.74	8	565.46	3.04	8	514.67	3.34
35	755.60	2 275	10	701.63	2.45	10	625.09	2.75	10	563.60	3.05	10	513.13	3.35
36	753 95	2.28	12	698.78	2.46	12	622 83	2.76	12	561.76	3.06	12	511.61	3.36
37	752.30	2.285	14	695.95	2.47	14	620.58	2 77	14	559.93	3.07	14	510.09	3.37
38	750 66	2.29	16	693.14	2.48	16	618.35	2.78	16	558.12	3.08	16	508.58	3.38
39	749 02	2 295	18	690.36	2.49	18	616.13	2.79	18	556.31	3.09	18	507.08	3.39
40	747.39	2.3	20	687.60	2.5	20	613.91	2.8	20	554.52	3.1	20	505.59	3.4
41	745 77	2.305	22	684.86	2.51	22	611.74	2.81	22	552.73	3.11	22	504.11	3.41
42	744.16	2.31	24	682.14	2.52	24	609.57	2.82	24	550.96	3.12	24	502.63	3.42
43	742.55	2.315	26	679.45	2.53	26	607.42	2.83	26	549.20	3.13	26	501.17	3.43
44	740.95	2.32	28	676.77	2.54	28	605.28	2.84	28	547.45	3.14	28	499.71	3.44
45	739.36	2.325	30	674.12	2.55	30	603.16	2.85	30	545.72	3.15	30	498.26	3.45
46	737.77	2.33	32	671.48	2.56	32	601.05	2.86	32	543.99	3.16	32	496.82	3.46
47	736.19	2.335	34	668.87	2.57	34	598.95	2.87	34	542.27	3.17	34	495.39	3.47
48	734.62	2.34	36	666.28	2 58	36	596 88	2.88	36	540.56	3.18	36	493.97	3.48
49	733.05	2.345	38	663.71	2 59	38	594 81	2.89	38	538.87	3.19	38	492.55	3.49
50	731.49	2.35	40	661.15	2.6	40	592.76	2.9	40	537.19	3.2	40	491.14	3.5
51	729.94	2 355	42	658.62	2.61	42	590.72	2.91	42	535.52	3.21	42	489.74	3.51
52	728.39	2 36	44	656.11	2.62	44	588.70	2.92	44	533.85	3.22	44	488.35	3.52
53	726.85	2.365	46	653.61	2 63	46	586.69	2.93	46	532.20	3.23	46	486.97	3.53
54	725.32	2.37	48	651.14	2.64	48	584.69	2.94	48	530.56	3.24	48	485.59	3.54
55	723.79	2.375	50	648.68	2.65	50	582.71	2.95	50	528.92	3.25	50	484.23	3.55
56	722.27	2.38	52	646.24	2.66	52	580 74	2.96	52	527.30	3.26	52	482.87	3.56
57	720.76	2.385	54	643.82	2.67	54	578.79	2.97	54	525.69	3.27	54	481.51	3 57
58	719.25	2 39	56	641.42	2.68	56	576.85	2.98	56	524.09	3.28	56	480.17	3.58
59	717.75	2.395	58	639.01	2 69	58	574.92	2 99	58	522.49	3.29	58	478.83	3.59
60	716.25	2.4	60	636.67	2.7	60	573.00	3.	60	520.91	3.3	60	477.50	3.6

TABLE IV.—RADII, AND DEFLECTION ANGLES IN MINUTES PER FOOT OF LENGTH.

Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.	Deg. D	Radius R	Def. per Foot.
12° 0′	477.50	3.6	13° 0′	440.77	3.9	14° 0′	409.29	4.2	15° 0′	382.00	4.5	16° 0′	358.12	4.8	21° 0′	272.86	6.3
2	476.18	3.61	2	439.64	3.91	2	408.31	4.21	2	381.15	4.51	10	354.43	4.85	10	270.71	6.35
4	474.86	3.62	4	438.52	3.92	4	407.35	4.22	4	380.31	4.52	20	350 82	4.9	20	268.59	6.4
6	473.56	3.63	6	437.40	3.93	6	406.39	4.23	6	379.47	4.53	30	347.27	4.95	30	266.51	6.45
8	472.25	3.64	8	436.29	3.94	8	405.43	4.24	8	378.64	4.54	40	343.80	5.	40	264.46	6.5
10	470.96	3.65	10	435.19	3.95	10	404.47	4.25	10	377.80	4.55	50	340.40	5.05	50	262.44	6 55
12	469.67	3.66	12	434.09	3.96	12	403.52	4.26	12	376.97	4.56	17 0	337.06	5.1	22 0	260.45	6.6
14	468.39	3.67	14	433.00	3.97	14	402.58	4.27	14	376.15	4.57	10	333.79	5.15	10	258.50	6.65
16	467.12	3.68	16	431.91	3.98	16	401.64	4.28	16	375.33	4.58	20	330.58	5.2	20	256.57	6.7
18	465.85	3.69	18	430.83	3.99	18	400.70	4.29	18	374.51	4.59	30	327.44	5 25	30	254.67	6.75
20	464.60	3.7	20	429.75	4.	20	399.77	4.3	20	373.69	4.6	40	324.34	5.3	40	252.79	6.8
22	463.34	3.71	22	428.68	4.01	22	398.84	4.31	22	372.89	4.61	50	321.31	5.35	50	250.95	6.85
24	462.10	3.72	24	427.61	4.02	24	397.92	4.32	24	372.08	4.62	18 0	318.33	5.4	23 0	249.13	6.9
26	460.86	3.73	26	426.55	4.03	26	397.00	4.33	26	371.28	4.63	10	315.41	5.45	10	247.34	6.95
28	459.63	3.74	28	425.49	4.04	28	396.08	4.34	28	370.47	4.64	20	312.55	5.5	20	245.57	7.
30	458.40	3.75	30	424.45	4.05	30	395.17	4.35	30	369.68	4.65	30	309.73	5.55	30	243.83	7.05
32	457.18	3.76	32	423.40	4.06	32	394.27	4.36	32	368.89	4.66	40	306.96	5.6	40	242.11	7.1
34	455.97	3.77	34	422.36	4.07	34	393.37	4.37	34	368.09	4.67	50	304.24	5.65	50	240 42	7.15
36	454.76	3.78	36	421.32	4.08	36	392.46	4.38	36	367.31	4.68	19 0	301.58	5.7	24 0	238.75	7.2
38	453.56	3.79	38	420.30	4.09	38	391.57	4.39	38	366.53	4.69	10	298.96	5.75	10	237.10	7.25
40	452.37	3.8	40	419.27	4.1	40	390.68	4.4	40	365.75	4.7	20	296.38	5.8	20	235.48	7 3
42	451.18	3.81	42	418.25	4.11	42	389.80	4.41	42	364.97	4.71	30	293.85	5.85	30	233.88	7.35
44	450.00	3.82	44	417.23	4.12	44	388 92	4.42	44	364.20	4.72	40	291.36	5.9	40	232.30	7.4
46	448.82	3.83	46	416.22	4.13	46	388.04	4.43	46	363.43	4.73	50	288.91	5.95	50	230.74	7.45
48	447.66	3.84	48	415.22	4.14	48	387.16	4.44	48	362.66	4.74	20 0	286 50	6.	25 0	229.20	7.5
50	446.50	3.85	50	414.21	4.15	50	386.29	4.45	50	361.90	4.75	10	284.13	6.05	10	227.68	7.55
52	445.34	3.86	52	413.22	4.16	52	385.43	4.46	52	361.13	4.76	20	281.80	6.1	20	226.18	7.6
54	444.19	3.87	54	412.23	4.17	54	384.57	4.47	54	360.38	4 77	30	279 52	6.15	30	224.71	7.65
56	443.04	3.88	56	411.24	4.18	56	383.70	4.48	56	359 62	4.78	40	277.26	6.2	40	223.25	7.7
58	441.90	3.89	58	410.26	4.19	58	382.85	4.49	58	358.87	4.79	50	275.04	6.25	50	221.81	7.75
60	440.77	3.9	60	409.29	4.2	60	382.00	4.5	60	358.12	4.8	60	272.86	6.3	60	220.38	7.8

TABLE IV.—*Continued.*

Deg. *D*	Radius *R*	Def. per Foot.
26° 0′	220.38	7.8
10	218.98	7.85
20	217.60	7.9
30	216 23	7.95
40	214.88	8.
50	213.54	8.05
27	212.22	8.1
10	210.92	8.15
20	209.63	8.2
30	208.36	8.25
40	207.11	8.3
50	205.87	8.35
28	204.64	8 4
10	203.43	8.45
20	202.24	8.5
30	201.05	8.55
40	199.88	8.6
50	198.73	8.65
29	197.59	8.7
10	196.46	8.75
20	195.34	8.8
30	194.24	8.85
40	193.15	8.9
50	192.07	8.95
30	191.00	9.
10	189.94	9.05
20	188.90	9.1
30	187.87	9.15
40	186.85	9.2
50	185.84	9.25
60	184.84	9.3

TABLE V.—ARC EXCESS.

Deg. *D*	Actual Arc. One Sta.
0°	100.000
1	100.001
2	100.005
3	100.011
4	100.020
5	100.032
6	100.046
7	100.062
8	100.020
9	100.026
10	100.032
11	100.038
12	100.046
13	100.054
14	100.062
15	100.071
16	100.020
17	100.023
18	100.026
19	100.029
20	100.032
21	100.035
22	100.038
23	100.042
24	100.046
25	100.050
26	100.054
27	100.058
28	100 062
29	100.066
30	100.071

TABLE VI.—TANGENTS AND EXTERNALS FOR A 1° CURVE.

Angle Δ	Tangent *T*	External *E*	Angle Δ	Tangent *T*	External *E*
1°	50.00	.216	6°	300.29	7.863
10′	58.34	.296	10′	308 65	8.308
20	66.67	.386	20	317.01	8.762
30	75.01	.490	30	325 37	9.230
40	83.34	.605	40	333 73	9.710
50	91.68	.733	50	342.09	10.203
2	100.02	.873	7	350.46	10.707
10	108 35	1.024	10	358 82	11.224
20	116.69	1.187	20	367.19	11.753
30	125.03	1.364	30	375 56	12.295
40	133 37	1.551	40	383 93	12.847
50	141.70	1.751	50	392.30	13.413
3	150.04	1.963	8	400 68	13.992
10	158.38	2.187	10	409.05	14 583
20	166.73	2 425	20	417.43	15.185
30	175.06	2.674	30	425 81	15.800
40	183.41	2.934	40	434 19	16 427
50	191.75	3.207	50	442.57	17.067
4	200.09	3.492	9	450 96	17.719
10	208.44	3.790	10	459 35	18.383
20	216.78	4.099	20	467.73	19.059
30	225.13	4.420	30	476.12	19.748
40	233.47	4.754	40	484.52	20.447
50	241.82	5.100	50	492.91	21.162
5	250.17	5.458	10	501.31	21.887
10	258.53	5.829	10	509.71	22.625
20	266.87	6.211	20	518.11	23.376
30	275.23	6.605	30	526.51	24.139
40	283.58	7.013	40	534.92	24.918
50	291.94	7.433	50	543.32	25.703

TABLE VI.—TANGENTS AND EXTERNALS FOR A 1° CURVE.

Angle Δ	Tang. T	Extern. E	Angle Δ	Tang. T	Extern. E	Angle Δ	Tang. T	Extern. E	Angle Δ	Tang. T	Extern. E
11°	551.74	26.501	17°	856.35	63.638	23°	1165.8	117.39	29°	1481.9	188.52
10′	560.15	27.313	10′	864.87	64.904	10′	1174.5	119.13	10′	1490 8	190 75
20	568.56	28.138	20	873.40	66.182	20	1183.1	120.88	20	1499.7	193.00
30	576.98	28.976	30	881.93	67.474	30	1191.8	122.64	30	1508.6	195.26
40	585.40	29.825	40	890.46	68.780	40	1200.5	124.42	40	1517.5	197.54
50	593.82	30.687	50	899.00	70.096	50	1209.2	126.21	50	1526.4	199.83
12	602.25	31.562	18	907.54	71.425	24	1217 9	128.01	30	1535.4	202.13
10	610.67	32.449	10	916.08	72.768	10	1226.7	129.83	10	1544.3	204.45
20	619.10	33.349	20	924.63	74.123	20	1235.4	131.66	20	1553.2	206.79
30	627.53	34.261	30	933.18	75.492	30	1244 1	133.50	30	1562.2	209.13
40	635.97	35.184	40	941.74	76.873	40	1252.8	135.36	40	1571.1	211.49
50	644.41	36.121	50	950.30	78.268	50	1261.6	137.24	50	1580.1	213.87
13	652.85	37.070	19	958.87	79.676	25	1270.3	139.12	31	1589.1	216.26
10	661.29	38.033	10	967.44	81.097	10	1279.1	141.02	10	1598.0	218.67
20	669.74	39.008	20	976.01	82.530	20	1287.8	142.94	20	1607.0	221.09
30	678.19	39.995	30	984.59	83.977	30	1296.6	144.86	30	1616.0	223.52
40	686.64	40.995	40	993.18	85.436	40	1305.3	146.80	40	1625.0	225.97
50	695.09	42.007	50	1001.8	86.908	50	1314.1	148.76	50	1634.0	228.44
14	703.55	43.031	20	1010.4	88 395	26	1322.9	150.72	32	1643.1	230.92
10	712.02	44.068	10	1018.9	89.893	10	1331.7	152.70	10	1652.1	233 41
20	720.48	45.119	20	1027.5	91.405	20	1340.4	154 70	20	1661.1	235.92
30	728.95	46.181	30	1036.1	92.930	30	1349.2	156.71	30	1670.1	238.44
40	737.42	47.256	40	1044.8	94.468	40	1358.0	158.73	40	1679.2	240.98
50	745.89	48.343	50	1053.4	96.019	50	1366.8	160.77	50	1688.2	243.53
15	754.37	49.443	21	1062.0	97.584	27	1375.7	162.82	33	1697.3	246.09
10	762.85	50.557	10	1070.6	99.161	10	1384.5	164.88	10	1706.4	248.68
20	771.33	51.683	20	1079.2	100.75	20	1393.3	166.96	20	1715.4	251.28
30	779.82	52.820	30	1087.9	102.35	30	1402.1	169.06	30	1724.5	253.89
40	788.30	53.972	40	1096.5	103.97	40	1411.0	171.16	40	1733.6	256.52
50	796.80	55.135	50	1105.2	105.60	50	1419.8	173.28	50	1742.7	259.16
16	805.29	56.312	22	1113.8	107.24	28	1428.6	175.42	34	1751.8	261.81
10	813.80	57.501	10	1122.4	108.90	10	1437.5	177.56	10	1761.0	264.49
20	822.30	58.708	20	1131.1	110.57	20	1446.4	179.73	20	1770.1	267.17
30	830.81	59.917	30	1139.8	112.26	30	1455.2	181.90	30	1779.2	269.87
40	839.32	61.145	40	1148.4	113.95	40	1464.1	184.09	40	1788.4	272.59
50	847.88	62.386	50	1157.1	115.66	50	1473.0	186.30	50	1797.5	275.32

TABLE VI.—TANGENTS AND EXTERNALS FOR A 1° CURVE.

Angle Δ	Tang. T	Extern. E	Angle Δ	Tang. T	Extern. E	Angle Δ	Tang. T	Extern. E	Angle Δ	Tang. T	Extern. E
35°	1806.7	278 07	41°	2142.4	387.40	47°	2491.5	518.23	53°	2856.9	672.70
10′	1815.8	280.83	10′	2151.9	390.74	10′	2501.4	522.19	10′	2867.3	677.36
20	1825.0	283 61	20	2161.4	394.09	20	2511.3	526.17	20	2877.7	682.03
30	1834.2	286.41	30	2170.9	397.46	30	2521.3	530.16	30	2888.2	686.73
40	1843.4	289.21	40	2180.5	400.84	40	2531.2	534.18	40	2898.6	691.44
50	1852.6	292.04	50	2190.0	404.24	50	2541.2	538.21	50	2909.1	696.17
36	1861.8	294.88	42	2199.5	407.67	48	2551.2	542.27	54	2919.6	700.93
10	1871.0	297.73	10	2209.1	411.10	10	2561.2	546.34	10	2930.1	705.70
20	1880.2	300.60	20	2218.7	414.55	20	2571.2	550.43	20	2940.6	710.50
30	1889.5	303.49	30	2228.3	418.02	30	2581.2	554.54	30	2951.2	715 32
40	1898.7	306.39	40	2237.8	421.50	40	2591.2	558.66	40	2961.7	720.16
50	1908.0	309.31	50	2247.5	425.00	50	2601.2	562.81	50	2972.3	725.02
37	1917.2	312.24	43	2257.1	428.53	49	2611.3	566.97	55	2982.9	729.90
10	1926.5	315.19	10	2266.7	432.06	10	2621.4	571.15	10	2993.5	734.80
20	1935.8	318.15	20	2276 4	435 62	20	2631.5	575.36	20	3004.1	739.72
30	1945.1	321.14	30	2286.1	439.19	30	2641.6	579.58	30	3014.7	744.67
40	1954.4	324.13	40	2295.7	442.77	40	2651.7	583.82	40	3025.4	749.63
50	1963.7	327.14	50	2305.4	446.38	50	2661.8	588.08	50	3036.0	754.62
38	1973.0	330.17	44	2315.1	449.99	50	2672.0	592.36	56	3046.7	759.63
10	1982.3	333.21	10	2324.8	453.64	10	2682.1	596.65	10	3057.4	764.66
20	1991.7	336.27	20	2334.5	457.30	20	2692.2	600.97	20	3068.1	769.71
30	2001.0	339.35	30	2344.2	460.98	30	2702.4	605.31	30	3078.8	774.78
40	2010.4	342.43	40	2353.9	464.67	40	2712.6	609.66	40	3089.6	779.87
50	2019.7	345.54	50	2363.7	468.38	50	2722.9	614.04	50	3100.4	784.99
39	2029.1	348.66	45	2373.4	472.11	51	2733.1	618.43	57	3111.1	790.13
10	2038.5	351.80	10	2383.2	475.85	10	2743.3	622.84	10	3121.9	795.29
20	2047.9	354.96	20	2393.0	479.62	20	2753.6	627.28	20	3132.8	800.47
30	2057.3	358.13	30	2402.8	483.40	30	2763.8	631.73	30	3143.6	805.67
40	2066 7	361.32	40	2412.6	487.19	40	2774.1	636.20	40	3154.4	810.90
50	2076.1	364.52	50	2422.4	491.01	50	2784.4	640.70	50	3165.3	816.15
40	2085.6	367.74	46	2432.2	494.84	52	2794.7	645.21	58	3176.2	821.42
10	2095.0	370.97	10	2442 1	498.69	10	2805.0	649.74	10	3187.1	826.71
20	2104.4	374.23	20	2451.9	502.57	20	2815.4	654.29	20	3198.0	832.08
30	2113.9	377.50	30	2461.8	506.45	30	2825.7	658.87	30	3209.0	837.37
40	2123.4	380.78	40	2471.7	510.36	40	2836.1	663.46	40	3219.9	842.78
50	2132.9	384.08	50	2481.6	514.28	50	2846.5	668.07	50	3230.9	848.11

59°		3241.9	853.52	65°		3650.4	1064.0	71°		4087.2	1308.3	77°		4557.9	1591.7
	10′	3252.9	858.94		10′	3662.1	1070.3		10′	4099.7	1315.6		10′	4571.5	1600.2
	20	3263.9	864.40		20	3673.9	1076.6		20	4112.4	1323.0		20	4585.1	1608.7
	30	3275.0	869.87		30	3685.7	1083.0		30	4125.0	1330.4		30	4598.8	1617.3
	40	3286.0	875.35		40	3697.5	1089.4		40	4137.7	1337.8		40	4612.5	1625.8
	50	3297.1	880.88		50	3709.3	1095.8		50	4150.4	1345.2		50	4626.3	1634.5
60		3308.2	886.43	66		3721.1	1102.3	72		4163.1	1352.7	78		4640.1	1643.1
	10	3319.3	892.00		10	3733.0	1108.7		10	4175.8	1360.2		10	4653.9	1651.9
	20	3330.5	897.59		20	3744.9	1115.2		20	4188.6	1367.7		20	4667.7	1660.6
	30	3341.6	903.21		30	3756.8	1121.7		30	4201.4	1375.3		30	4681.6	1669.4
	40	3352.8	908.85		40	3768.7	1128.3		40	4214.2	1382.9		40	4695.5	1678.2
	50	3364.0	914.51		50	3780.6	1134.9		50	4227.1	1390.5		50	4709.5	1687.0
61		3375.2	920.19	67		3792.6	1141.5	73		4240.0	1398.1	79		4723.4	1695.9
	10	3386.5	925.90		10	3804.6	1148.1		10	4252.9	1405.8		10	4737.5	1704.8
	20	3397.7	931.63		20	3816.6	1154.7		20	4265.8	1413.6		20	4751.5	1713.8
	30	3409.0	937.39		30	3828.7	1161.4		30	4278.8	1421.3		30	4765.6	1722.8
	40	3420.3	943.17		40	3840.7	1168.1		40	4291.8	1429.1		40	4779.7	1731.8
	50	3431.6	948.98		50	3852.8	1174.9		50	4304.8	1436.9		50	4793.9	1740.9
62		3442.9	954.81	68		3864.9	1181.6	74		4317.9	1444.7	80		4808.1	1750.0
	10	3454.3	960.66		10	3877.1	1188.4		10	4330.9	1452.6		10	4822.3	1759.2
	20	3465.7	966.54		20	3889.2	1195.3		20	4344.1	1460.5		20	4836.5	1768.3
	30	3477.1	972.45		30	3901.4	1202.1		30	4357.2	1468.5		30	4850.8	1777.6
	40	3488.5	978.37		40	3913.6	1209.0		40	4370.4	1476.5		40	4865.1	1786.8
	50	3499.9	984.33		50	3925.9	1215.9		50	4383.6	1484.5		50	4879.5	1796.1
63		3511.4	990.30	69		3938.1	1222.8	75		4396.8	1492.5	81		4893.9	1805.5
	10	3522.8	996.30		10	3950.4	1229.8		10	4410.0	1500.5		10	4908.3	1814.8
	20	3534.3	1002.3		20	3962.7	1236.8		20	4423.3	1508.7		20	4922.8	1824.3
	30	3545.8	1008.4		30	3975.0	1243.8		30	4436.7	1516.9		30	4937.3	1833.7
	40	3557.4	1014.5		40	3987.4	1250.9		40	4450.0	1525.0		40	4951.8	1843.2
	50	3568.9	1020.6		50	3999.8	1257.9		50	4463.4	1533.2		50	4966.4	1852.8
64		3580.5	1026.7	70		4012.2	1265.0	76		4476.8	1541.5	82		4981.0	1862.3
	10	3592.1	1032.9		10	4024.6	1272.2		10	4490.2	1549.8		10	4995.7	1872.0
	20	3603.7	1039.0		20	4037.1	1279.4		20	4503.7	1558.1		20	5010.4	1881.6
	30	3615.4	1045.2		30	4049.6	1286.6		30	4517.2	1566.4		30	5025.1	1891.3
	40	3627.0	1051.5		40	4062.1	1293.8		40	4530.7	1574.8		40	5039.8	1901.1
	50	3638.7	1057.7		50	4074.6	1301.0		50	4544.3	1583.2		50	5054.6	1910.8

TABLE VI.—TANGENTS AND EXTERNALS FOR A 1° CURVE.

Angle Δ	Tangent T	External E	Angle Δ	Tangent T	External E	Angle Δ	Tangent T	External E	Angle Δ	Tangent T	External E
83°	5069.5	1920.7	88°	5533.4	2235.7	93°	6038.2	2591.2	98°	6591.6	3004.0
10′	5084.4	1930.5	10′	5549.5	2246.9	10′	6055 8	2607.0	10′	6611.0	3018.6
20	5099.3	1940 4	20	5565.7	2258.1	20	6073.4	2619.8	20	6630.5	3033.3
30	5114.2	1950.4	30	5581 9	2269.4	30	6091.2	2632.7	30	6650.0	3048.1
40	5129.2	1960.4	40	5598.2	2280.8	40	6109 0	2645.7	40	6669.6	3063.0
50	5144.3	1970.4	50	5614 4	2292.2	50	6126.8	2658.7	50	6689.2	3077.9
84	5159.3	1980.5	89	5630.9	2303.7	94	6144.7	2671.8	99	6709 0	3092 9
10	5174.4	1990.6	10	5647.3	2315.2	10	6162.6	2684.9	10	6728.8	3107.9
20	5189.6	2000.8	20	5663.7	2326.7	20	6180.6	2698.1	20	6748.6	3123.1
30	5204.8	2011.0	30	5680.2	2338.3	30	6198.7	2711.4	30	6768.6	3138.3
40	5220.0	2021.2	40	5696.8	2350 0	40	6216.8	2724 7	40	6788.6	3153.5
50	5235.3	2031.5	50	5713.4	2361.7	50	6235.0	2738.0	50	6808.6	3168.9
85	5250.6	2041.9	90	5730.0	2373.5	95	6253 2	2751.5	100	6828.7	3184.3
10	5265 9	2052.2	10	5746.7	2385.3	10	6271.5	2765.0	10	6849.0	3199.8
20	5281.3	2062.7	20	5763.4	2397.1	20	6289.8	2778.5	20	6869.2	3215.4
30	5296.8	2073.1	30	5780.2	2409.0	30	6308.2	2792 1	30	6889 6	3231.0
40	5312 2	2083.6	40	5797.1	2421.0	40	6326.7	2805.8	40	6910.0	3246.7
50	5327.8	2094.2	50	5814.0	2433.0	50	6345.2	2819.6	50	6930.5	3262.5
86	5343.3	2104.8	91	5830 9	2445.1	96	6363.8	2833.4	101	6951.1	3278.3
10	5358.9	2115.4	10	5847.8	2457.2	10	6382.5	2847.2	10	6971 7	3294.3
20	5374.6	2126.1	20	5864.9	2469.4	20	6401.2	2861.1	20	6992.4	3310.3
30	5390.3	2136.9	30	5882.0	2481.6	30	6419.9	2875.1	30	7013.2	3326.4
40	5406.0	2147 7	40	5899.2	2493.9	40	6438.8	2889 2	40	7034.0	3342.5
50	5421.8	2158.5	50	5916.4	2506.3	50	6457.6	2903.3	50	7055.0	3358.7
87	5437.6	2169.4	92	5933.6	2518.6	97	6476 6	2917.5	102	7076.0	3375.1
10	5453.4	2180.3	10	5950.9	2531.1	10	6495 6	2931.7	10	7097.0	3391.5
20	5469 3	2191.3	20	5968.2	2543 6	20	6514 7	2946 1	20	7118.2	3407.9
30	5485 3	2202.3	30	5985.6	2556.2	30	6533.8	2960 4	30	7139.4	3424.5
40	5501.3	2213.4	40	6003 1	2568.8	40	6553.0	2974.9	40	7160.7	3441.1
50	5517.3	2224.5	50	6020.6	2581.5	50	6572.3	2989.4	50	7182.2	3457.8

TABLE VI.—TANGENTS AND EXTERNALS FOR A 1° CURVE.

Angle Δ	Tangent T	External E	Angle Δ	Tangent T	External E	Angle Δ	Tangent T	External E	Angle Δ	Tangent T	External E
103°	7208.6	3474.6	108°	7886.7	4018.5	113°	8657.1	4651.6	118°	9536.3	5395.4
10′	7225.2	3491.5	10′	7910.9	4038.0	10′	8684.5	4674.5	10′	9567.8	5422.4
20	7246.8	3508.4	20	7935.1	4057.7	20	8712.0	4697.5	20	9599.5	5449.6
30	7268.5	3525.5	30	7959.5	4077.5	30	8739.7	4720.6	30	9631.3	5476.9
40	7290.3	3542.6	40	7983.9	4097.3	40	8767.5	4743.9	40	9663.2	5504.4
50	7312.1	3559.8	50	8008.5	4117.3	50	8795.4	4767.2	50	9695.3	5532.0
104	7334.1	3577.0	109	8033.2	4137.4	114	8823.4	4790.7	119	9727.6	5559.8
10	7356.1	3594.4	10	8057.9	4157.5	10	8851.6	4814.4	10	9760.0	5587.8
20	7378.2	3611.9	20	8082.8	4177.8	20	8879.9	4838.1	20	9792.7	5615.9
30	7400.4	3629.4	30	8107.8	4198.2	30	8908.3	4862.0	30	9825.4	5644.2
40	7422.7	3647.0	40	8132.8	4218.6	40	8936.8	4886.0	40	9858.3	5672.6
50	7445.0	3664.8	50	8158.0	4239.3	50	8965.5	4910.2	50	9891.4	5701.3
105	7467.5	3682.6	110	8183.3	4260.0	115	8994.3	4934.4	120	9924.7	5730.0
10	7490.0	3700.4	10	8208.7	4280.8	10	9023.3	4958.9	10	9958.1	5759.0
20	7512.6	3718.4	20	8234.2	4301.7	20	9052.3	4983.4	20	9991.7	5788.1
30	7535.3	3736.5	30	8259.8	4322.7	30	9081.5	5008.1	30	10025.4	5817.4
40	7558.1	3754.6	40	8285.5	4343.8	40	9110.8	5032.9	40	10059.3	5846.8
50	7581.0	3772 9	50	8311.3	4365.1	50	9140.3	5057.9	50	10093.5	5876.5
106	7604.0	3791.2	111	8337.2	4386.4	116	9169.9	5083.0			
10	7627.0	3809.6	10	8363.2	4407.8	10	9199.7	5108.2			
20	7650.2	3828.2	20	8389.4	4429.5	20	9229.6	5133.6			
30	7673.4	3846.8	30	8415.6	4451.2	30	9259 6	5159.1			
40	7696.7	3865.4	40	8442.0	4473.0	40	9289.8	5184.8			
50	7720.2	3884.2	50	8468.5	4494.9	50	9320.1	5210.6			
107	7743.7	3903.1	112	8495.1	4516.9	117	9350.5	5236.6			
10	7767.3	3922.1	10	8521.8	4539.1	10	9381.1	5262.6			
20	7791.0	3941.2	20	8548.6	4561.3	20	9411.9	5288.9			
30	7814.8	3960.4	30	8575.6	4583 8	30	9442.7	5315.3			
40	7838.6	3979.6	40	8602.6	4606.2	40	9473.8	5341.8			
50	7862.6	3999.0	50	8629.8	4628.9	50	9505.0	5368.5			

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